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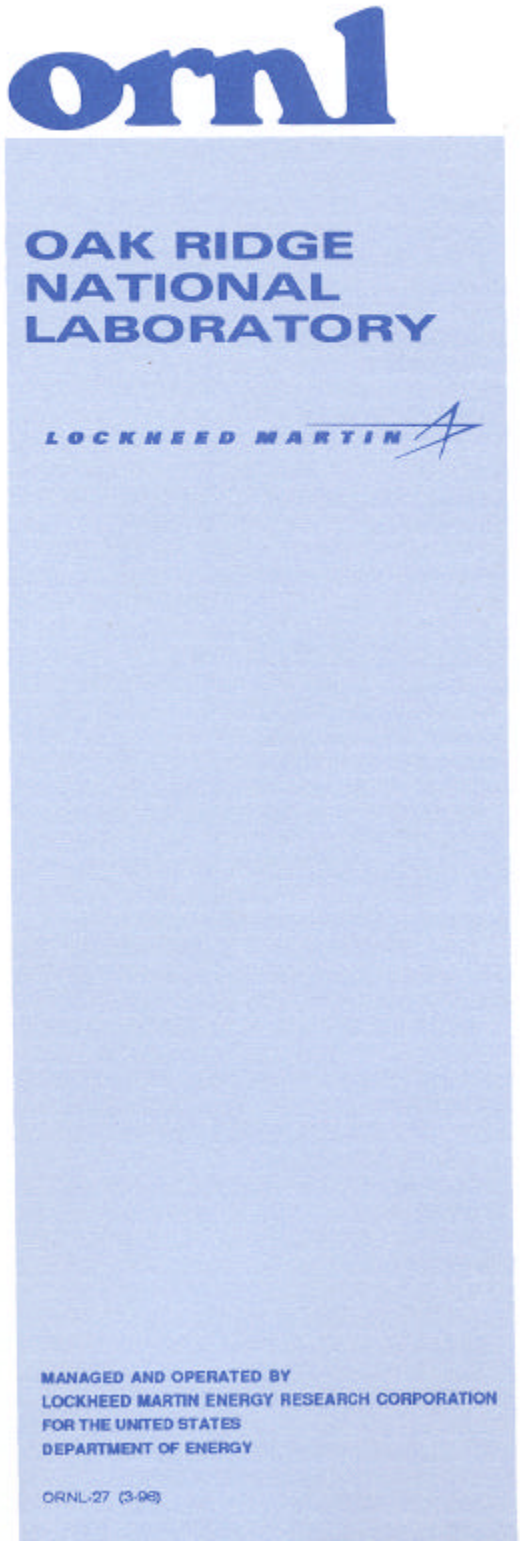

SCALE-4 Analysis of LaSalle Unit 1 BWR Commercial Reactor Critical Configurations

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ORNL/TM-1999/247

Computational Physics and Engineering Division (10)

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Date Published: March 2000

Prepared by the
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LOCKHEED MARTIN ENERGY RESEARCH CORP.
for the
U.S. DEPARTMENT OF ENERGY
under contract DE-AC05-96OR22464

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ABSTRACT

Five commercial reactor criticals (CRCs) for the LaSalle Unit 1 boiling-water reactor have been analyzed using KENO V.a, the Monte Carlo criticality code of the SCALE 4 code system. The irradiated fuel assembly isotopics for the criticality analyses were provided by the Waste Package Design team at the Yucca Mountain Project in the United States, who performed the depletion calculations using the SAS2H sequence of SCALE 4. The reactor critical measurements involved two beginning-of-cycle and three middle-of-cycle configurations. The CRCs involved relatively low-cycle burnups, and therefore contained a relatively high gadolinium poison content in the reactor assemblies. This report summarizes the data and methods used in analyzing the critical configurations and assesses the sensitivity of the results to some of the modeling approximations used to represent the gadolinium poison distribution within the assemblies. The KENO V.a calculations, performed using the SCALE 44GROUPNDF5 ENDF/B-V cross-section library, yield predicted k_{eff} values within about 1% $\Delta k/k$ relative to reactor measurements for the five CRCs using general 8-pin and 9-pin heterogeneous gadolinium poison pin assembly models.

1. INTRODUCTION

As part of an ongoing program to develop and validate the criticality safety analysis methodology for the disposal of commercial spent nuclear fuel by the U.S. Department of Energy Office of Civilian Radioactive Waste Management (OCRWM), commercial reactor criticality (CRC) data for the LaSalle Unit 1 (LS1) boiling-water reactor (BWR) have been compiled to provide a database for code validation studies involving BWR-type fuel assemblies.[1]

The critical reactor configurations for LS1 have been analyzed using the KENO V.a Monte Carlo criticality analysis code,[2] developed as part of the SCALE system.[3] The reactor critical measurements were all performed following reactor shutdown, either at the beginning-of-cycle (BOC) or after a reactor trip during a cycle. The reactor conditions and state at the time the reactor first attains criticality is referred to as a statepoint (SP). These states involve zero-power conditions and are attained after sufficient cooling time to allow the fission product xenon inventory to decay. A total of five statepoints have been analyzed: two involving BOC conditions, and the remaining three involving a cycle burnup of less than 8000 MWd/MTU.

The GE8×8NB-type fuel assemblies in the LS1 reactor incorporate an integral burnable gadolinia (Gd_2O_3) poison in some of the fuel pins. The statepoint criticals were performed at BOC, or relatively low-cycle burnups, and consequently these measurements involved a significant number of reactor fuel assemblies with high concentrations of the burnable poison still present. The presence of gadolinium poison in the assemblies introduces a significant level of heterogeneity in the calculations. In addition, the critical statepoints were achieved with approximately 70% insertion of the boron carbide (B_4C) control blades in the core, making these highly heterogeneous critical configurations.

The primary objective of this report is to provide an independent criticality assessment of the LS1 statepoint criticals to verify previous analyses performed by the Yucca Mountain Project Waste Package Design team under OCRWM. The irradiated fuel assembly isotopics for the criticality analyses were obtained directly from the Waste Package Design team and served as a common reference point for the analyses. This report summarizes the calculated results obtained using KENO V.a, discusses the methods and approximations used in the criticality assessment model, and provides a brief discussion of the sensitivity of the criticality results to the methods and approximations used in representing the integrated burnable gadolinia rods in the assemblies.

2. REACTOR DESCRIPTION

LaSalle Unit 1 is a General Electric BWR with a rated power of 3323 MWt. Control of reactivity is accomplished in part by a combination of control blade movements and integral burnable gadolinia (Gd_2O_3) absorbers. The core has a total of 185 control blades. The reactor vessel internal shroud is a stainless steel cylinder, which surrounds the reactor core and serves as a barrier to separate the upward flow of the coolant through the reactor core from the downward flow of the coolant outside the core.

This section describes the general LS1 reactor design information relevant to the reactor configuration during the SP measurements and includes the fuel assembly design, control blade design, and fuel assembly compositions.

2.1. FUEL ASSEMBLY DESIGN DESCRIPTION

The LS1 reactor core contains 764 fuel assemblies. All fuel assemblies used in the LS1 reactor critical SP measurements were of the GE8×8NB (GE9)-type, designed and manufactured by General Electric. The assembly has ferrule-type spacer grids, a large-diameter central water rod that spans four fuel pin positions, axially zoned enrichment, and integral burnable gadolinia (Gd_2O_3) absorbers. Additionally, this fuel assembly has a 12-in. natural uranium blanket at the top of the assembly. The fuel assembly and fuel channel specifications are listed in Table 1. Figure 1 illustrates the GE8×8NB fuel-assembly and control-blade arrangement. Figure 2 illustrates some of the axial detail of the assembly.

The burnable gadolinia (Gd_2O_3) poison in the GE8×8NB fuel assemblies is integrated with the enriched uranium in a limited number (between 7 and 12) of assembly pins to reduce the reactivity of the fuel during the initial phase of reactor operation. In general, the effect of the gadolinium poison on k_{eff} is most significant during the initial 10 GWd/MTU of operation, after which the gadolinium absorber has been typically depleted to low concentrations.

The axially zoned enrichment of the fuel assemblies is approximated using 10 axial zones to represent the axial depletion effects. The height of each axial zone and fuel zone identifiers for each assembly type residing in the reactor during the critical measurements (Cycles 7 and 8) are listed in Table 2. The table provides composition identifiers or "cross sections" for each axial zone of the nine assembly types that resided in the reactor core during the five-statepoint measurements. These identifiers are used to cross reference the actual fuel zone compositions and configurations which are listed in Table 3. The assembly types, characterized by their unique axial enrichment and gadolinium poison pin arrangement, are referenced by number (1, 2, 4, 5, and 8–12) and also by alphanumeric designations (A-H, and J).

Table 1. LaSalle Unit 1 fuel assembly and reactor data

Description	Data
Fuel assembly array size and type	GE8×8NB (GE9B)
Number of fuel pins / assembly	60 (enriched axial zones) 48 – 60 (natural uranium axial end zones)
Number of water rods / assembly	1
Number of assemblies in core	764
Number of control blades in core	185
System pressure	1020 psia (7.03266 MPa)
Active fuel height (H)	381.00 cm
Pin pitch	1.6256 cm
Assembly pitch (P)	15.24 cm
Fuel pin cladding outer diameter (OD)	1.2268 cm
Fuel pin cladding inner diameter (ID)	1.06426 cm
Fuel pin clad thickness	0.08128 cm
Fuel pin cladding material	Zircaloy
Fuel pellet diameter	1.04394 cm
Fuel material	UO_2
Water rod outside diameter	3.4036 cm
Water rod inside diameter	3.2004 cm
Water rod material	Zircaloy
Channel - inner width	13.4061 cm
- thickness Cycles 4–7	0.254 cm
- thickness Cycle 8	0.203 cm
Channel material	Zircaloy

Table 2. Fuel assembly descriptions for 10 axial zones

		Cross-Section Reference Number by Zone								
Axial zone	Length (cm)	Type 8 (B) fuel	Type 9 (A) fuel	Type 10 (C) fuel	Type 11 (D) fuel	Type 12 (E) fuel	Type 1 (G) fuel	Type 2 (F) fuel	Type 4 (J) fuel	Type 5 (H) fuel
10 (Top)	15.24	106	100	112	127	122	117	145	145	139
9	15.24	107	101	113	128	123	150	134	146	140
8	45.72	108	102	114	129	124	118	135	147	141
7	45.72	109	103	115	130	125	119	136	148	142
6	45.72	110	104	115	131	126	120	137	149	143
5	45.72	110	104	115	131	126	120	137	149	143
4	45.72	110	104	115	131	126	120	137	149	143
3	60.96	111	105	116	132	124	121	138	147	144
2	45.72	111	105	116	132	124	121	138	147	144
1 (Bottom)	15.24	107	101	113	128	123	150	134	146	140
Total	381.0									

Table 3. Fuel assembly cross-section properties

Cross section ID	Number of fuel pins	Average enrichment (wt % ^{235}U)	Number of gadolinia pins	Gadolinia enrichment (wt %)	Channel thickness (in.)
100	48	0.71	0	0	0.100
101	60	0.71	0	0	0.100
102	60	3.50	4 / 6	5.0 / 4.0	0.100
103	60	3.65	6 / 6	5.0 / 4.0	0.100
104	60	3.65	4 / 6	5.0 / 4.0	0.100
105	60	3.50	7 / 3	5.0 / 4.0	0.100
106	49	0.71	0	0	0.100
107	60	0.71	0	0	0.100
108	60	3.23	9	3.0	0.100
109	60	3.37	2 / 9	4.0 / 3.0	0.100
110	60	3.37	9	3.0	0.100
111	60	3.23	5/4	4/3	0.100
112	51	0.71	0	0	0.100
113	60	0.71	0	0	0.100
114	60	3.27	4 / 5	5.0 / 4.0	0.100
115	60	3.38	4 / 5	5.0 / 4.0	0.100
116	60	3.27	9	5.0	0.100
117	49	0.71	0	0	0.100
150	60	0.71	0	0	0.100
118	60	3.45	9	4.0	0.100
119	60	3.62	2 / 9	5.0 / 4.0	0.100
120	60	3.62	9	4.0	0.100
121	60	3.45	5 / 4	5.0 / 4.0	0.100
122	51	0.71	0	0	0.100
123	60	0.71	0	0	0.100
124	60	3.39	7	4.0	0.100
125	60	3.50	9	4.0	0.100
126	60	3.50	7	4.0	0.100
127	51	0.71	0	0	0.100
128	60	0.71	0	0	0.100
129	60	3.39	2 / 5	4.0 / 3.0	0.100
130	60	3.50	4 / 5	4.0 / 3.0	0.100
131	60	3.50	2 / 5	4.0 / 3.0	0.100
132	60	3.39	7	4.0	0.100
133	51	0.71	0	0	0.100
134	60	0.71	0	0	0.100
135	60	3.46	7	4.0	0.100
136	60	3.58	2 / 7	5.0 / 4.0	0.100
137	60	3.58	7	4.0	0.100
138	60	3.46	4 / 3	5.0 / 4.0	0.100
139	50	0.71	0	0	0.080
140	60	0.71	0	0	0.080
141	60	3.63	8	4.0	0.080
142	60	3.88	2 / 8	5.0 / 4.0	0.080
143	60	3.88	8	4.0	0.080
144	60	3.63	8	5.0	0.080
145	48	0.71	0	0	0.080
146	60	0.71	0	0	0.080
147	60	3.63	10	5.0	0.080
148	60	3.90	12	5.0	0.080
149	60	3.90	10	5.0	0.080

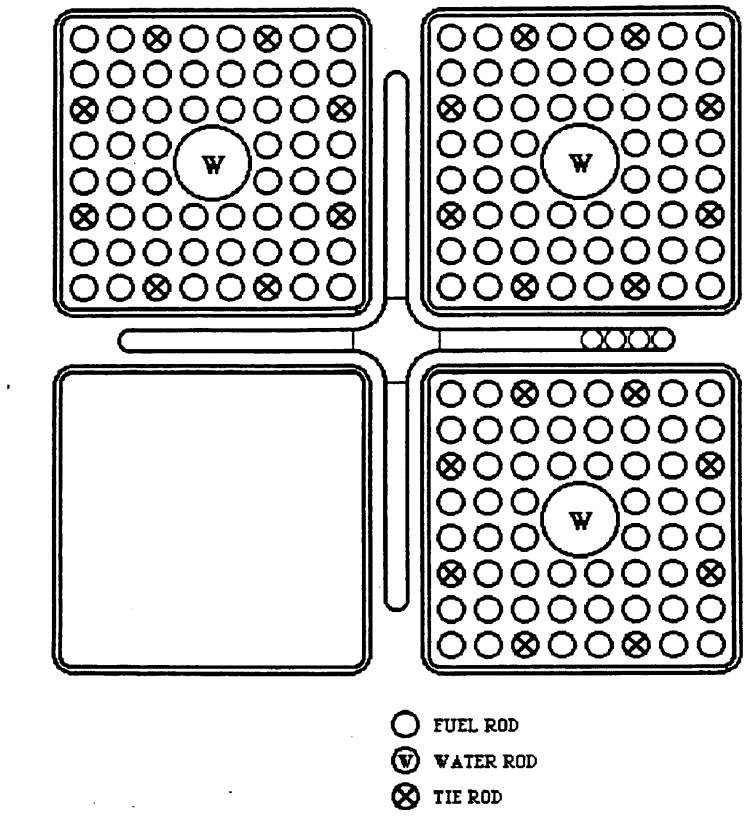


Fig. 1. GE8 ´8NB assemblies and control blade arrangement.

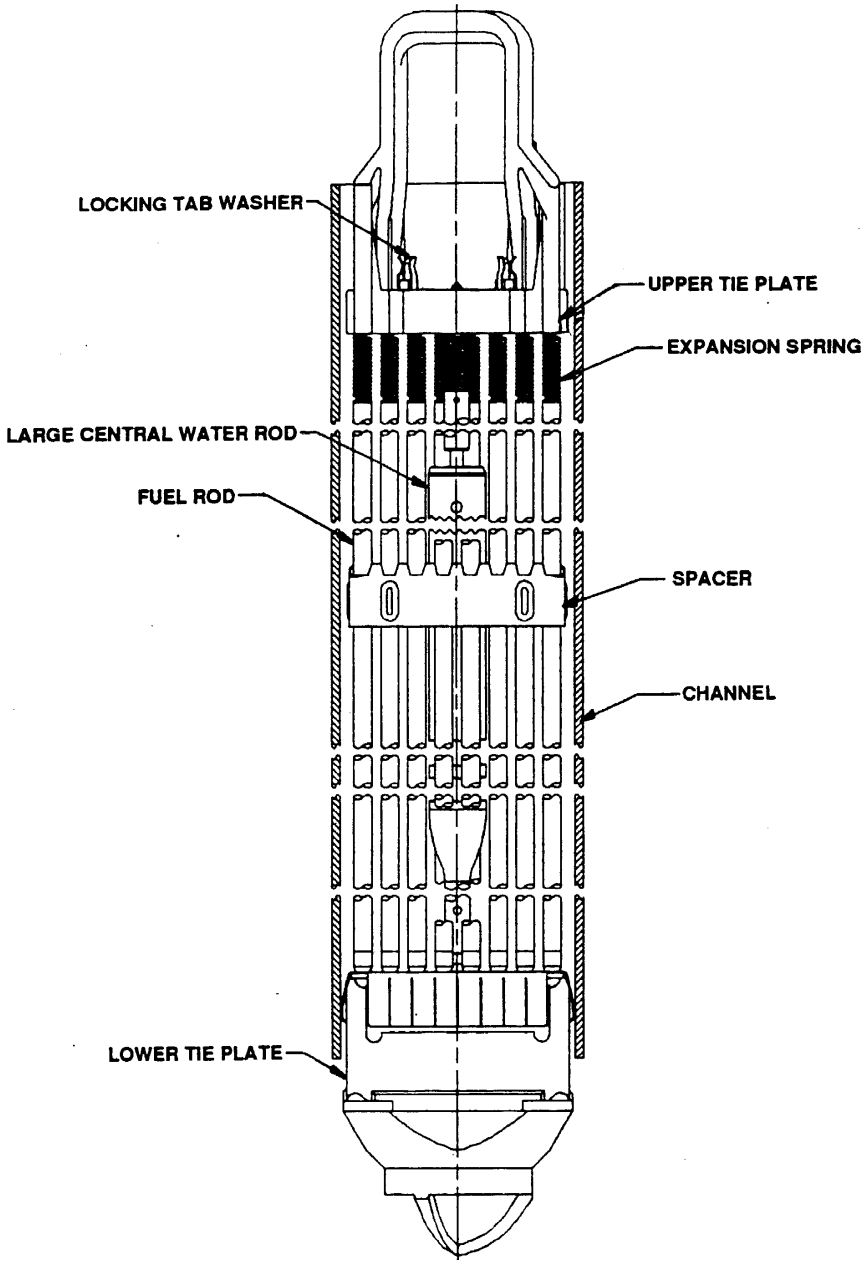


Fig. 2. GE8´8NB assembly axial section.

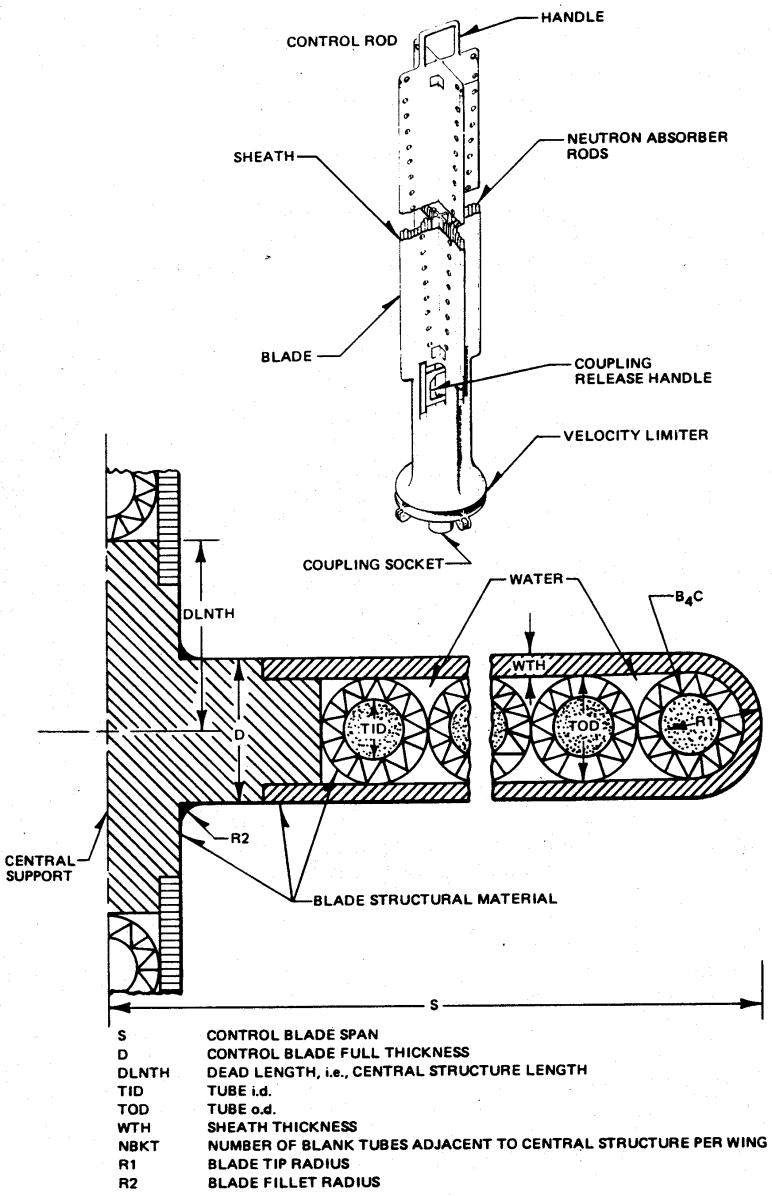
2.2. CONTROL BLADES

The control blades used in LS1 during the statepoint criticals are bottom-entry blades having a cruciform shape (see Fig. 1). Each control blade has 84 stainless steel tubes containing B_4C as the active absorbing material. The reactor contains a total of 185 control blades, sufficient to cover most of the assembly groups (4 assemblies) in the core. The control-blade specifications were obtained from EPRI Report NP-240 (ref. 4) and are listed in Table 4. The control-blade design is shown in Fig. 3, and the arrangement of the blades with respect to the reactor core (bottom entry) is shown in Fig. 4.

In general, criticality is achieved with about 70 to 75% blade insertion (i.e., 25 to 30% of the blades withdrawn) for the cold critical conditions of the statepoint measurements. During full-power operation, however, significantly fewer control blades are required due to the changes in reactor conditions.

Table 4. Control blade specifications

Parameter	Specification
Shape	Cruciform
Structural material	SS-304
Control material	B_4C in SS-304 tubes
B_4C density (g/cm^3)	70.6% theoretical density = 1.78 g/cm^3 (0.706 H 2.52 g/cm^3)
Boron isotopic distribution	Natural abundance ^{10}B (18.431 wt %), ^{11}B (81.569 wt %)
Active control length (cm)	363.2
Number of tubes per control blade group	84 (21 per individual blade)
Inner diameter of B_4C tubes (mm)	3.505
Outside diameter of tube sheath (mm)	4.775
Control blade full thickness (mm)	7.925
Control blade full span – from center (mm)	123.83
Control blade sheath thickness (mm)	1.422
Control blade inner thickness (mm)	5.081
Control blade inside length (mm)	102.55



S	CONTROL BLADE SPAN
D	CONTROL BLADE FULL THICKNESS
DLNTH	DEAD LENGTH, i.e., CENTRAL STRUCTURE LENGTH
TID	TUBE i.d.
TOD	TUBE o.d.
WTH	SHEATH THICKNESS
NBKT	NUMBER OF BLANK TUBES ADJACENT TO CENTRAL STRUCTURE PER WING
R1	BLADE TIP RADIUS
R2	BLADE FILLET RADIUS

Fig. 3. B_4C control-blade assembly.

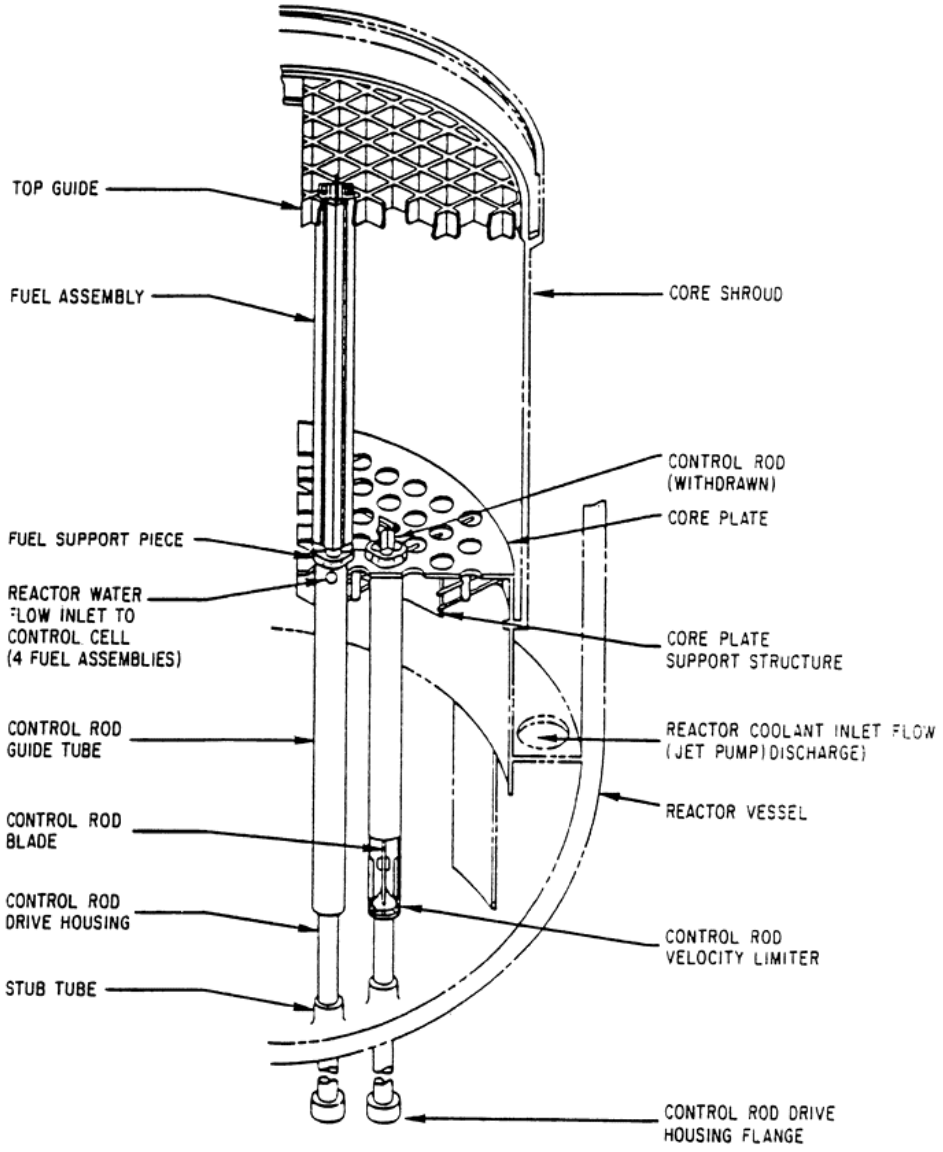


Fig. 4. LS1 reactor core structure and control-blade arrangement.

3. LASALLE UNIT 1 CRITICAL STATEPOINT DATA

A reactor SP is defined as a point at which a reactor first achieves criticality during the startup (e.g., the critical state at the BOC or a restart during cycle operation). For restarts, these points are obtained after sufficient time following a reactor trip to allow the transient fission product xenon poison to decay. The reactor is considered to be at zero power at the statepoint, and thus there is no appreciable buildup of short-lived fission products associated with normal reactor operation. The reactor coolant temperature at the statepoints, and therefore the density, is also more closely associated with cold conditions than normal operating conditions.

3.1. REACTOR STATEPOINT CONDITIONS

This report assesses five reactor statepoints measured for the LS1 reactor. The SP data include the BOC of Cycle 7, two restarts during Cycle 7, the BOC for Cycle 8, and one restart during Cycle 8. A summary of the measured reactor conditions at each of the five reactor statepoints (designated SP7 – SP11) is provided in Table 5. The cycle number, the effective full-power days (EFPDs) during the cycle at which the startup occurred, the elapsed time since the reactor was shutdown, moderator temperature, and measured neutron multiplication factor (slightly supercritical based on the reactor period at the time of the statepoint), are provided for each statepoint.

3.2. FUEL ASSEMBLY CONFIGURATION

The LS1 reactor core contains a total of 764 fuel assemblies. The core loading configuration is approximately eighth-core symmetric, in general, because the control blades are moved in eighth-core symmetry. The analysis applied core symmetry to reduce the number of assemblies required for the depletion calculations from 764 to 119 assemblies for the Cycle 7 statepoints, and 116 assemblies for the Cycle 8 statepoints. The LS1 assembly configuration for the Cycle 7 statepoint criticals is shown in Fig. 5, and the configuration for the Cycle 8 statepoints is shown in Fig. 6. The nonsymmetric assemblies are shown explicitly in the quarter-core layout in the figures. The assembly sites shown in these figures with no assembly designation are eighth-core symmetric. The assembly types for each alphanumeric designation are defined in Table 2.

3.3. CONTROL CONFIGURATION

Figures 7 through 11 provide the LS1 core maps with the control blade group positions for each statepoint. Each box in the figures represents a control blade site (see Fig. 1) that includes four fuel assemblies.

The control blade positions in these figures are given in units of “notches” withdrawn. A notch represents 7.62 cm (3 in.) of blade movement. A “0” in a control blade site indicates the blade is fully inserted (from the bottom), with the bottom of the blade aligned with the bottom of the active fuel assembly. A total of 48 notch positions represent 365.8 cm; of axial control blade

coverage. The total active fuel length is 381.0 cm; therefore, with the blades fully inserted, the upper 15.2 cm of the fuel is not bladed. This portion of the GE8×8NB assemblies contains only natural enrichment uranium fuel. A control blade at position 20 indicates the blades are withdrawn, or lowered, 20 notches (152.4 cm) below the fully inserted position. A double-dash "--" in a control blade site represents a blade that is fully withdrawn. In general, about 140 of the 185 total control blades are fully inserted in the core at statepoint criticality.

Table 5. Statepoint criticality data

State point	Cycle	Criticality date (m/d/y)	Burnup (MWd/MTU)	EFPD	Down time (h)	k_{eff} [a]	Moderator temperature (K)	Reactor period (s)
SP7	7	06/24/94	0.00	0.00	3024	1.00584	330.2	147
SP8	7	02/14/95	4728.4	193.20	120	1.00519	369.3	166
SP9	7	06/17/95	7507.28	306.75	140	1.00875	378.4	420
SP10	8	04/21/96	0.00	0.00	2064	1.00605	342.5	130
SP11	8	05/16/96	89.8	3.67	120	1.00574	351.2	327

[a] k_{eff} determined from the measured reactor period.

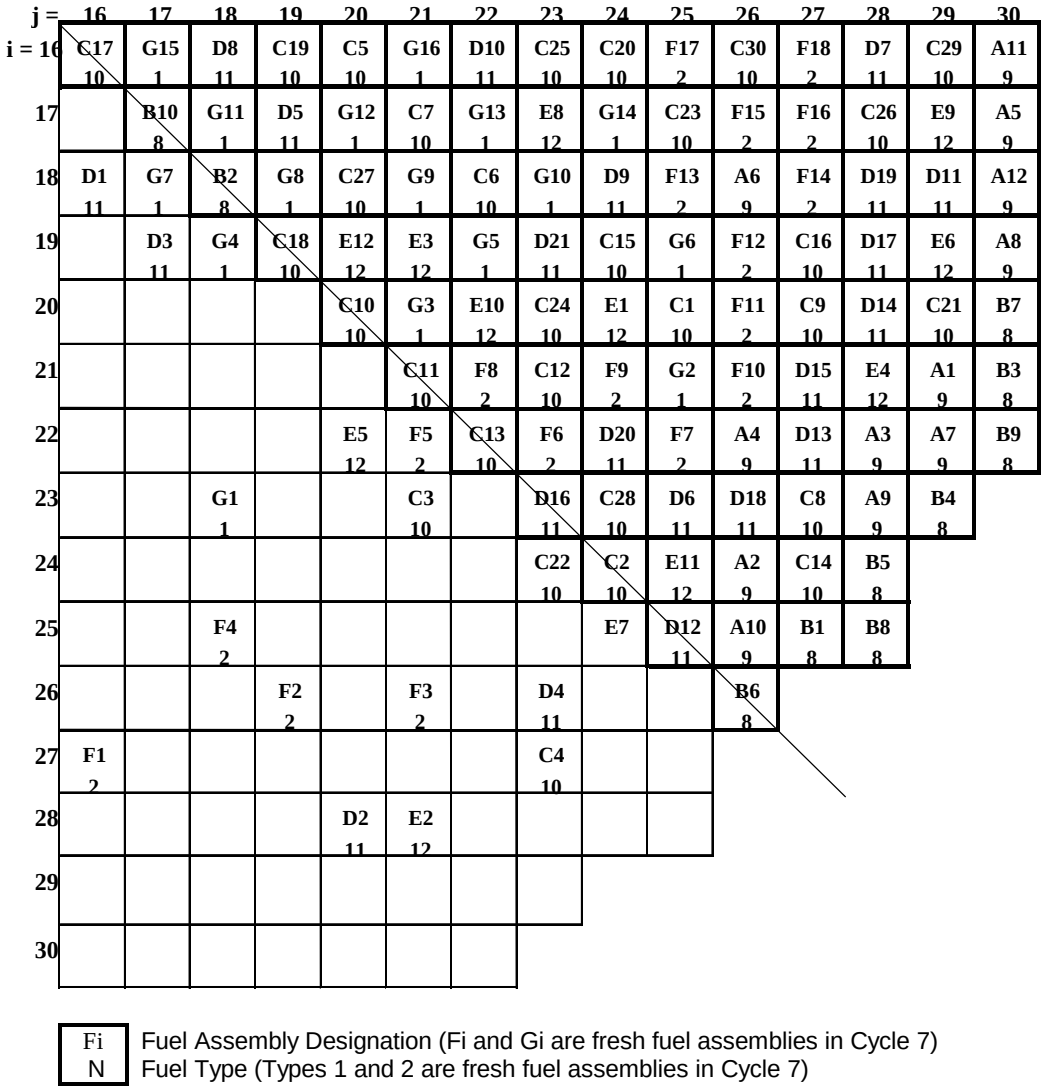
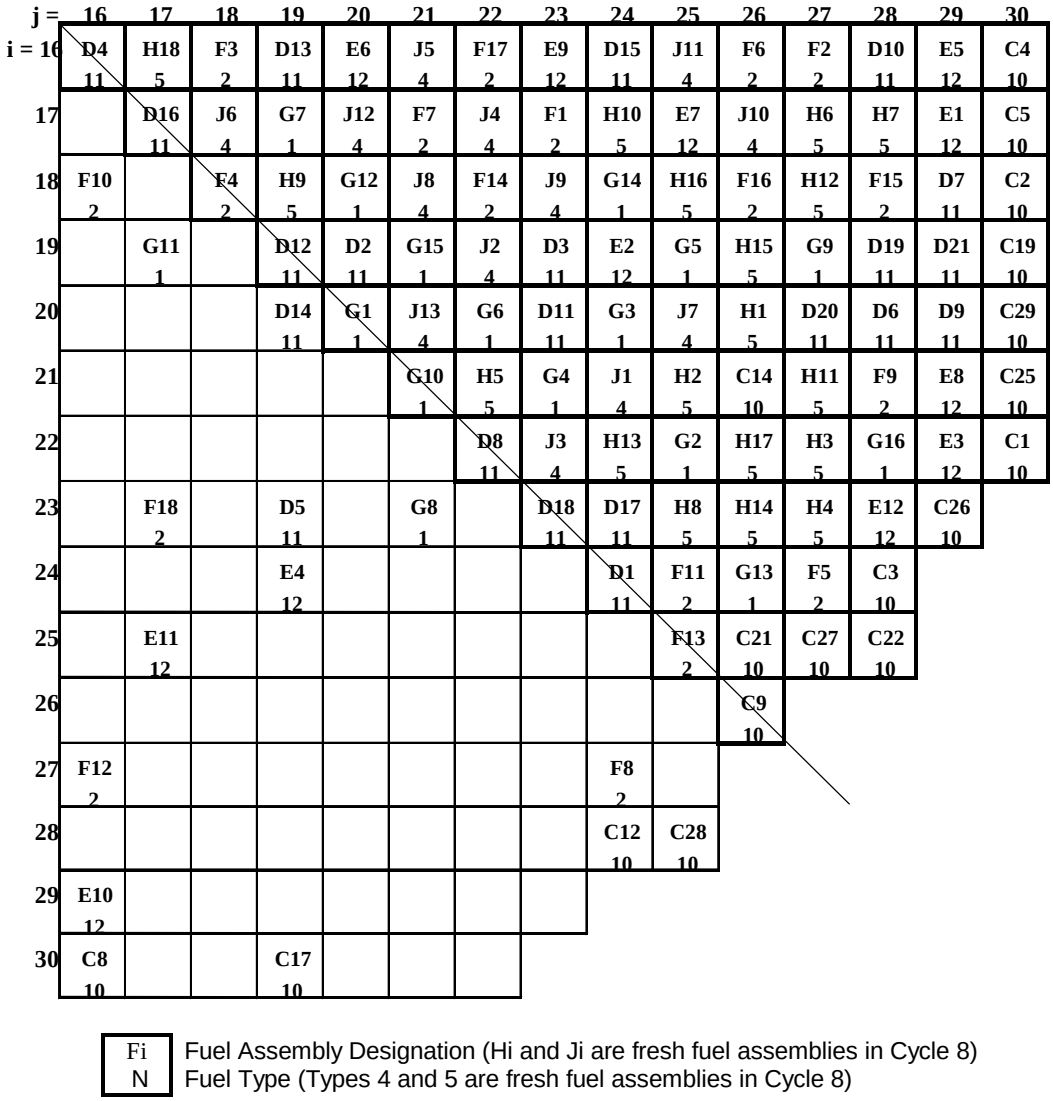


Fig. 5. LS1 assembly locations for the Cycle 7 statepoint criticals.



Fi N	Fuel Assembly Designation (Hi and Ji are fresh fuel assemblies in Cycle 8) Fuel Type (Types 4 and 5 are fresh fuel assemblies in Cycle 8)

Fig. 6. LS1 assembly locations for the Cycle 8 statepoint criticals.

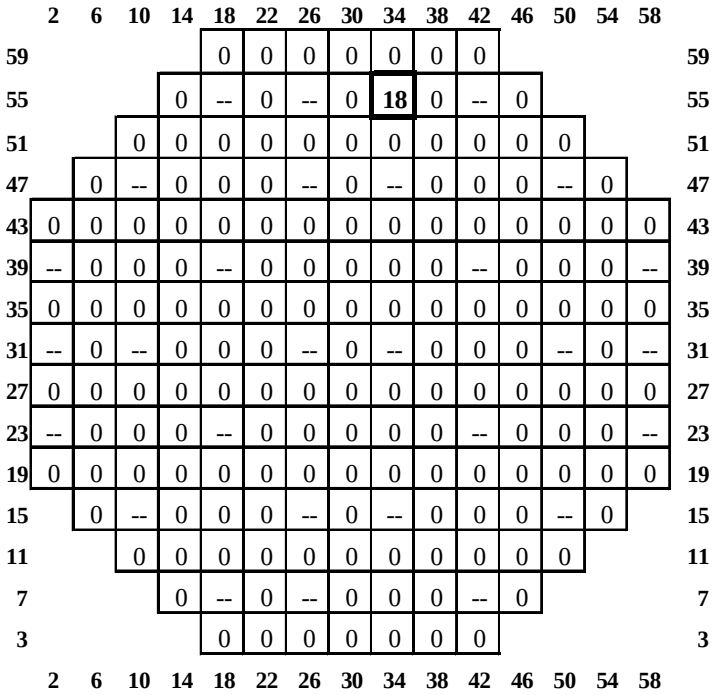


Fig. 7. LS1 SP7 criticality control-blade configuration.

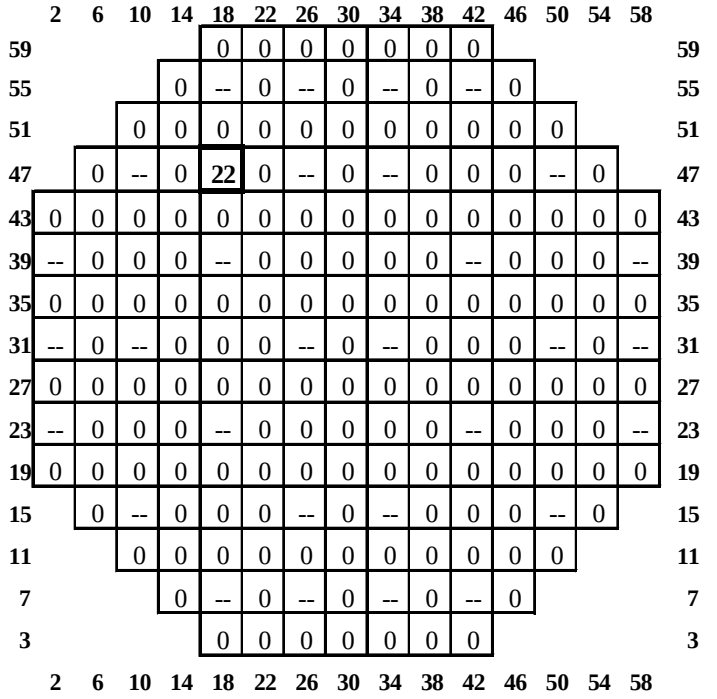


Fig. 8. LS1 SP8 criticality control-blade configuration.

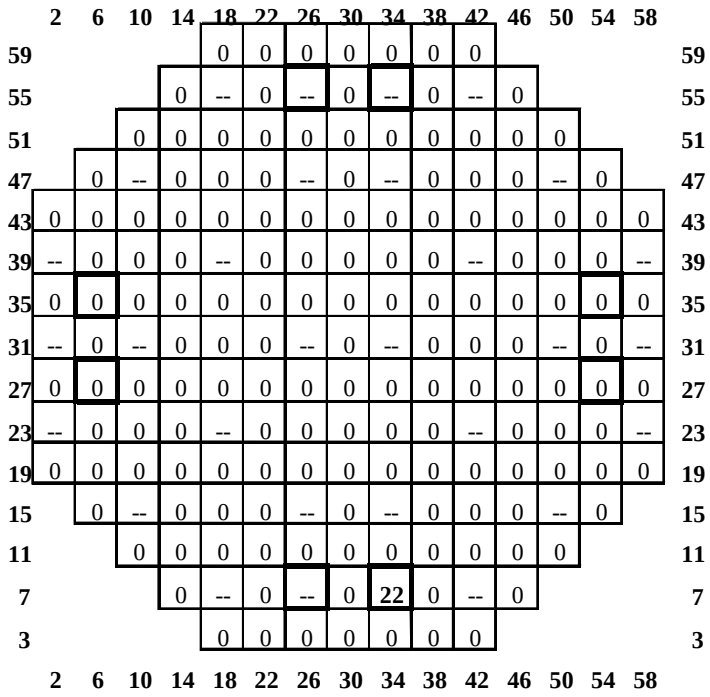


Fig. 9. LS1 SP9 criticality control-blade configuration.

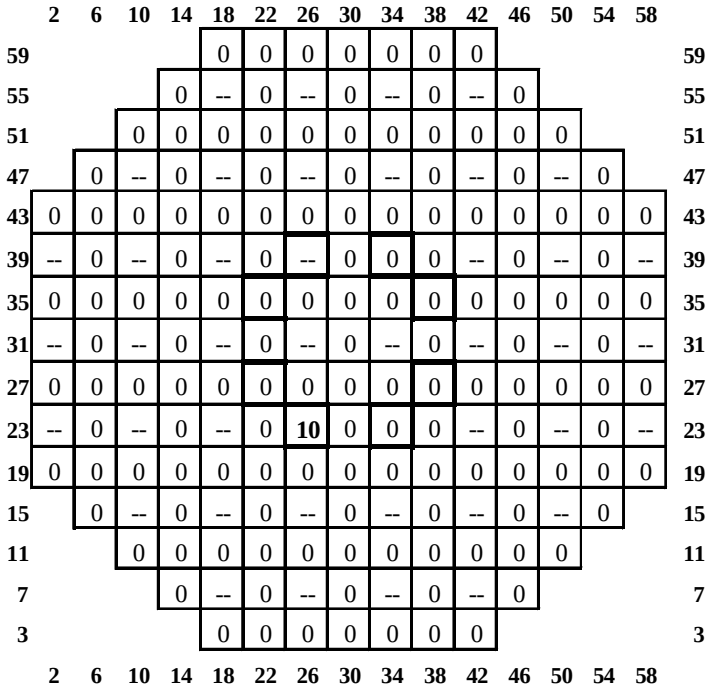


Fig. 10. LS1 SP10 criticality control-blade configuration.

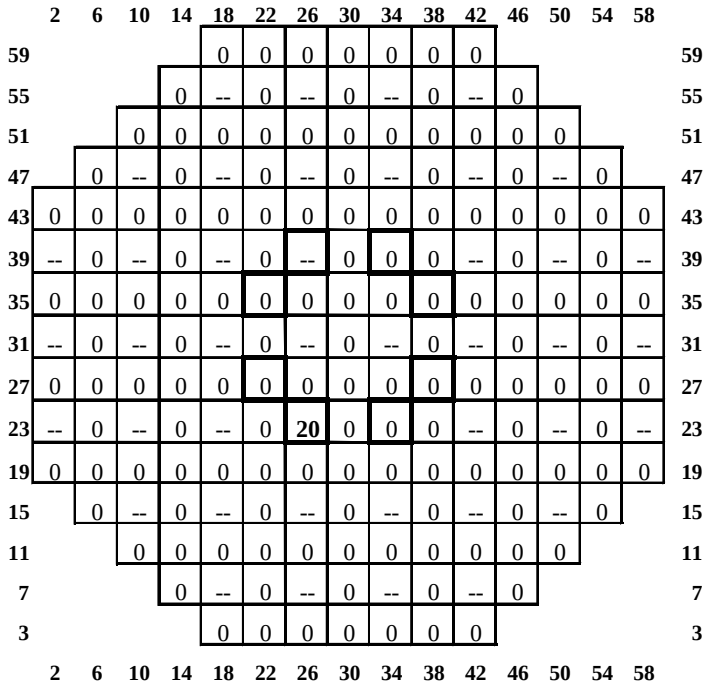


Fig. 11. LS1 SP11 criticality control-blade configuration.

4. CRITICALITY ANALYSES

This section discusses the KENO V.a criticality analysis models, fuel assembly composition data processing, cross-section processing, and the approximations used in the criticality analysis of the LS1 statepoint critical configurations.

4.1. OVERVIEW OF THE METHODOLOGY

The reactor criticality analyses were performed using a full-core model of the LS1 reactor with the Monte Carlo criticality code KENO V.a and the 44GROUPNDF5 cross-section library.[5] The quasi eighth-core symmetry applied in the calculation of the irradiated fuel assembly compositions was also applied in the criticality calculations. This method reduced the number of unique assemblies from 764 to 119 for the Cycle 7 criticals, and 116 for the Cycle 8 criticals. The axial burnup variation of the assemblies was represented using 10 axial zones. Each criticality calculation therefore involved approximately 1200 unique-composition assembly zones.

Irradiated fuel compositions were not calculated as part of this study, but were generated by the Yucca Mountain Project Waste Package Design team.[6] The depletion calculations were made using the SAS2H sequence of the SCALE 4 code system. These calculations followed the complete irradiation history for the assemblies that resided in the core for each of the SP measurements, during all cycles leading up to the measurements. The composition data were transmitted as data files consisting mainly of ORIGEN-S output for each fuel zone of each assembly.

The criticality analysis methodology involved the following steps:

1. obtaining the irradiated fuel assembly nuclide compositions from the data files,
2. processing the data into units and formats suitable for input to the SCALE Material Information Processor routines,
3. generating cross sections for each assembly axial zone based on the zone compositions and geometry using the Critical Safety Analysis Sequence CSASI,
4. preparing the KENO V.a full-core model based on the assembly locations and control blade configurations for the statepoints, and
5. using the KENO V.a model to calculate the effective multiplication factor k_{eff} for the system, and compare the results against the measured value.

4.2. CODE VERSIONS AND COMPUTER PLATFORM

The cross-section processing and criticality calculations were performed using the SCALE 4.4 code system, run on a DEC Alpha Workstation. Cross-section processing was performed using CSASI, version 4.3, and criticality calculations were performed using KENO V.a, version 4.1.

4.3. LS1 FUEL ASSEMBLY COMPOSITIONS

The fuel assembly compositions for each axial zone of the unirradiated fuel assemblies in the BOC critical configurations (SP7 and SP10) were obtained from the assembly composition data in Tables 2 and 3 All other assembly compositions were obtained from ref. 6.

The assembly locations in the Cycles 7 and 8 statepoint criticals are shown in the quarter-core layout in Figs. 5 and 6, respectively. The Cycle 7 core had 208 fresh fuel assemblies of type F and G; the Cycle 8 core had 248 fresh assemblies of type H and J. The assembly sites in these figures that have no assembly designation are symmetric in the one-eighth core. The nonsymmetric assemblies are shown in the lower quadrant of the core layout and were explicitly represented in the criticality model. Even though the reactor is quarter-core assembly symmetric, the KENO V.a model used in the analyses was based on a full-core representation in order to accurately capture the nonsymmetric control blade configuration.

4.4. COMPOSITION DATA PROCESSING

The irradiated fuel compositions[6] were calculated by ORIGEN-S and archived primarily as the SAS2H[7] input and ORIGEN-S[8] output files, for each axial fuel zone of each fuel assembly. These files were processed as part of this work to extract the inventories into a format suitable for input to CSASI[9] cross-section processing sequence and ultimately for use the criticality calculation using KENO V.a.

The mass (gram) inventories from the ORIGEN-S calculations were extracted from the output files and processed into atomic number densities using a utility code GECKO (Get Compositions for KENO from ORIGEN) written for this analysis, which automatically determined the total fuel volume for the case from the number of pins per assembly, the active fuel length, and fuel pin diameter. A listing of this utility is provided in Appendix B. The gram inventories represent the average compositions over all fuel pins, including any integrated burnable poison pins in the assembly. The gram quantities (M) were converted to atom density (ADEN) in units of atoms/(b-cm) using the equation

$$\mathrm{ADEN} = \frac{\mathrm{M} \times 0.60225}{\mathrm{AWT} \times \mathrm{V}} \quad ,$$

where AWT is the atomic weight for the nuclide, and V is the total fuel volume. A limitation in obtaining the assembly inventories from the ORIGEN-S output files is that the inventories are printed to only two significant figures. This factor could potentially result in an error in composition specification of up to 0.5% for a given nuclide due to roundoff. For a fissile actinide such as ^{235}U, this could result in an error in the neutron multiplication factor, where the calculational biases are typically at the percent level. It is recommended that either the binary ORIGEN-S composition interface, or the SAS2H card-image interface, be used in future assessments to store fuel compositions.

Since the number of nuclides in the ORIGEN-S nuclear database is much larger than that in the 44GROUPNDF5 cross-section library used with KENO V.a, automated selection criteria were applied during the processing. The criteria used by GECKO to select the actinide and fission product nuclides from the ORIGEN-S output were:

1. the nuclide must reside on the 44GROUPNDF5 cross-section library, and
2. the atomic number density must be greater than 10^{-8} atoms/(b-cm).

For the light-element tables, only gadolinium and europium (decay product) were selected. The burnable poisons are tracked by ORIGEN-S in the SAS2H depletion analysis as light elements, which allows the burnable-poison inventory to be determined separately from fission products for regions containing both burnable poison and fissionable material. This method has a particular importance to BWR-type CRC analyses in that it allows the burnable poison inventory to be determined separately from the fission product gadolinium, and distributed heterogeneously in only the gadolinium poison pins, allowing a more detailed assembly representation for the criticality calculations. To obtain the correct concentrations in the burnable poison rods the volume (V) used to derived the number densities must be adjusted to include only the poison rods.

The initial concentration of oxygen (as ^{16}O in the fuel) was not available from the ORIGEN-S output since it was omitted as a light-element input specification in the SAS2H input. The oxygen was therefore added automatically to each case by the GECKO utility at a fixed nominal atomic number density of 4.5497×10^{-2} atoms/b-cm.

The water-moderator density for each of the statepoints was based on the statepoint temperatures listed in Table 5 by interpolating on standard density tables for a system pressure of 1000 psia. The moderator densities for the SP7 – SP11 analyses were 0.9882, 0.9649, 0.9583, 0.9818, and 0.9768 g/cm^3, respectively.

4.5. CROSS-SECTION PROCESSING

Neutron cross sections for the criticality analyses were obtained from the SCALE 44GROUPNDF5 library, a 44-group neutron cross-section library based on ENDF/B-V data, with ENDF/B-VI evaluations for ^{16}O, ^{154}Eu, and ^{155}Eu. The 44GROUPNDF5 library was developed specifically for criticality safety calculations involving LWR fuel.

The cross sections were processed for the KENO V.a criticality analyses using the Criticality Safety Analysis Sequence CSASI, a control sequence within the CSAS4 control module of SCALE. The CSASI sequence uses the BONAMI code to apply the Bondarenko resonance self-shielding method for nuclides with Bondarenko data; it then invokes NITAWL-II to perform Nordheim resolved resonance self-shielding corrections using the specified problem-dependent temperature. The microscopic cross sections for the nuclides in each mixture are subsequently combined in CSASI using the ICE module of SCALE to create a macroscopic cross section for each mixture. This step reduced significantly the number of cross sections handled by KENO V.a for a statepoint calculation.

For each statepoint calculation, approximately 1200 sequential CSASI runs (BONAMI/NITAWL-II/ICE) were performed to generate the macroscopic cross sections for

each assembly zone. The macroscopic cross sections incorporate the number densities and temperature for each fuel zone, and therefore no composition specifications were required in the KENO V.a case. Following each CSASI run, the WAX utility module was run to assign a unique cross-section identifier to the set based on the assembly ID (e.g., D4, J12, etc.) and axial position, and then append the cross section to a working library to build a single set of cross sections required for the criticality problem.

During the cross-section library processing, an undocumented array dimensional limit was exceeded in WAX, requiring a fix in WAX to handle up to the approximately 2400 cross-section sets needed for the heterogeneous assembly statepoint calculations. A typical CSASI input case, generated by the GECKO utility code, is listed in Appendix A. The GECKO code listing is given in Appendix B.

4.6. GE8 ´8NB ASSEMBLY MODEL

The GE8×8NB assemblies were assumed to have 60 pins in each axial fuel zone in the KENO V.a model. The natural enrichment uranium zones at each end of the assemblies actually contained between 48 and 60 pins. For these zones the number densities of the fuel were adjusted in order to conserve the total mass of the zone (for fuel zones with less than 60 pins). The actinide and fission product number densities within each zone were assumed to be spatially uniform over all assembly pins, and over the axial zone length.

The gadolinium poison was represented using two different assembly models, one that homogenized the poison in all of the assembly pins, and the other that explicitly represented the burnable poison pins in the assembly. In the homogeneous model, the gadolinium poison was simply distributed uniformly over all 60 pins of the fuel assembly.

In the heterogeneous model the gadolinium poison was placed in a limited number of pins as UO_2/Gd_2O_3 pins. The actual number of gadolinia pins per assembly axial zone is provided in Table 3, and ranges from 7 to 12 pins per assembly. However, the exact configuration of the pins in the assembly is proprietary information and was not available to ORNL. For the purposes of this study, the discrete pin model assumed 8 gadolinia pins per assembly in the criticality calculations. The pins were distributed symmetrically in the central ring of fuel pins, near the four corners of the assembly, as shown in Fig. 12. Although this is not the actual pin configuration, this model is assumed to be generally representative of BWR assemblies and sufficient to assess the importance of a heterogeneous poison pin representation for CRC calculations involving gadolinium poison-bearing assemblies.

The number densities of the gadolinium poison isotopes (and europium decay daughters) were calculated by GECKO using an assembly volume based on 8 poison pins per assembly for the heterogeneous assembly model.

The assembly fuel pin spacer grids were not included in the KENO V.a model since there was insufficient design information available to include them. The Zircaloy channels were modeled with a single thickness of 0.203 cm (0.08 in.), corresponding to the thickness of the Cycle 8 fuel assemblies.

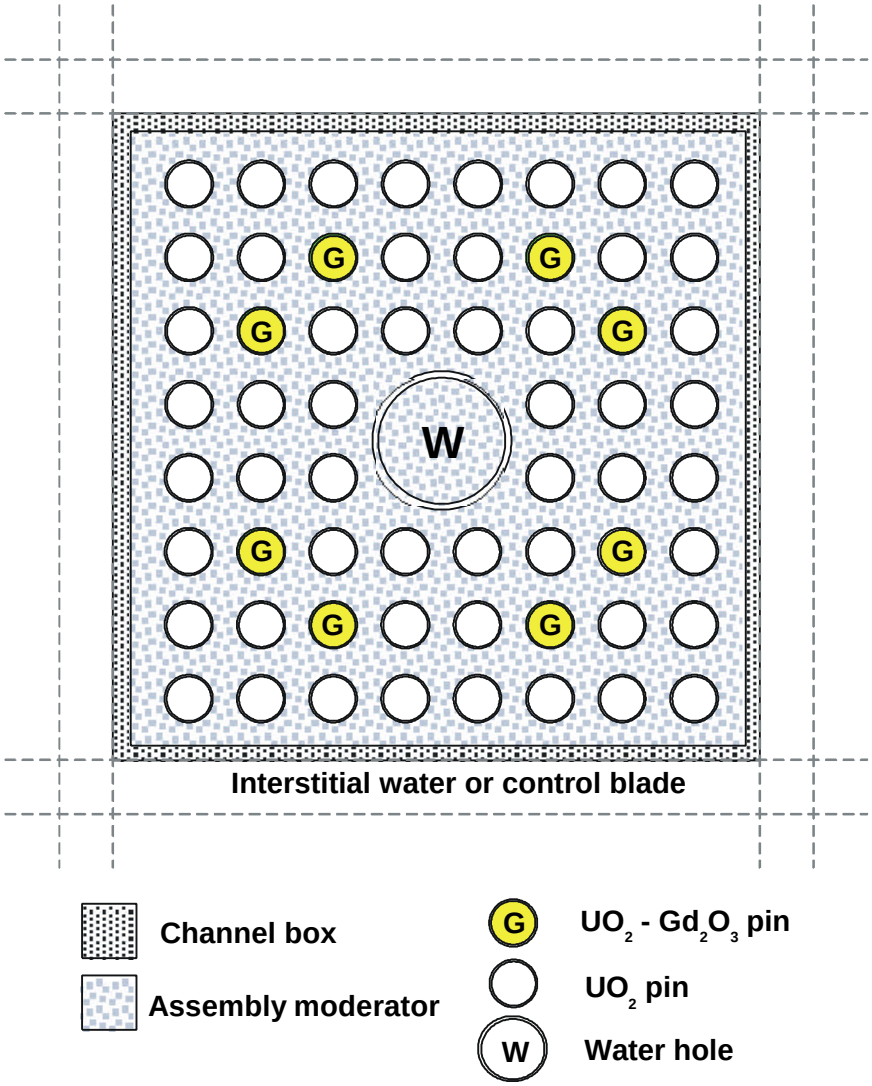


Fig. 12. KENO V.a GE8 ´8NB assembly model.

4.7. LASALLE UNIT 1 REACTOR MODEL

A KENO V.a full-core model of the LS1 reactor model was developed using the 10-axial-zone assembly representation adopted in the previous analyses.[1] The reactor model explicitly represented the 764 fuel assemblies in the core, plus the approximately 140 control blades inserted into the core during the critical measurements. The quasi eighth-core symmetry reduced the number of unique assembly zones (compositions) in the model to about 1200. For calculations that explicitly represented the burnable gadolinium pins in the assembly (8 pins per assembly), two mixtures per axial fuel zone were required – one for the UO_2 pins; the second, for the UO_2 / Gd_2O_3 pins.

Each assembly axial zone was modeled using 10 units in the KENO V.a model, resulting in a total of about 12,000 units to define the unique assemblies for the problem. In addition, each assembly required 6 array entries to define the fuel pin arrangements, or about 7,000 arrays for the problem. A utility code, LS1K, was written to automate the preparation of the mixture, geometry, and array data blocks for the KENO V.a input. An assembly map with the assembly locations for each statepoint is required by the LS1K utility. The LS1K utility code listing and the assembly map for Cycle 8 are provided in Appendix C.

After constructing the 10 units representing the 10 axial zones of an assembly, the units were stacked in a vertical array to form the complete assembly unit having a length of 381.0 cm. The assembly interstitial water (see Fig. 12) was modeled with units that spanned the full active length of the complete assembly (381.0 cm). The control blades were constructed with five units each, one for each blade, and one unit at the center of the cruciform. The 21 B_4C rods in each control blade were modeled explicitly in the control blade models. Two control blade models were assembled – one to represent the fully inserted control blades; the other, to represent the single critical height control blade. An assessment of the impact of approximating the B_4C rods as a homogeneous mixture (with steel tube sheath and water) within the control blades indicated that homogenization resulted in about a 1% decrease in the k_{eff} compared to explicitly modeling the B_4C rods. A cross-section illustration of the KENO V.a assembly group and control blade model is shown in Fig. 13.

After each unique assembly unit and the interstitial water units were defined, the core configuration was assembled as a 59×59 unit array using the assembly configurations for the respective cycles (see Figs. 5 and 6). Thirty of the 59 row (and column) positions in the array contain the assembly units, with the remaining 29 units in each assembly row (or column) representing the water units between the assemblies. Between each of the 30 rows containing the assembly units were units containing the interstitial water. The control blade units were subsequently added to the array based on the control blade patterns for each critical statepoint (see Figs. 7 through 11). An abridged KENO V.a model input listed for the Cycle 8 SP11 critical configuration is provided in Appendix D. The total size of the full-core model is about 70,000 lines (not all lines are included in listing). A section view of the reactor core for the Cycle 8 SP11 critical configuration is illustrated in Fig. 14 showing the control blade configuration at a core elevation of 100 cm. A subsection of the KENO V.a core model, obtained using the KENO3D geometry visualization program, is illustrated in Fig. 15.

The region surrounding the reactor core was not modeled in detail. Due to the large physical size of the reactor core (4.6-m diam), only about 0.5% of the neutrons leak from the system, and therefore a detailed treatment to accurately model the reflection from the out-of-core components was not warranted for this analysis. For the criticality analysis, the reactor core was surrounded by 30 cm of water to approximate the reflection conditions close to the core.

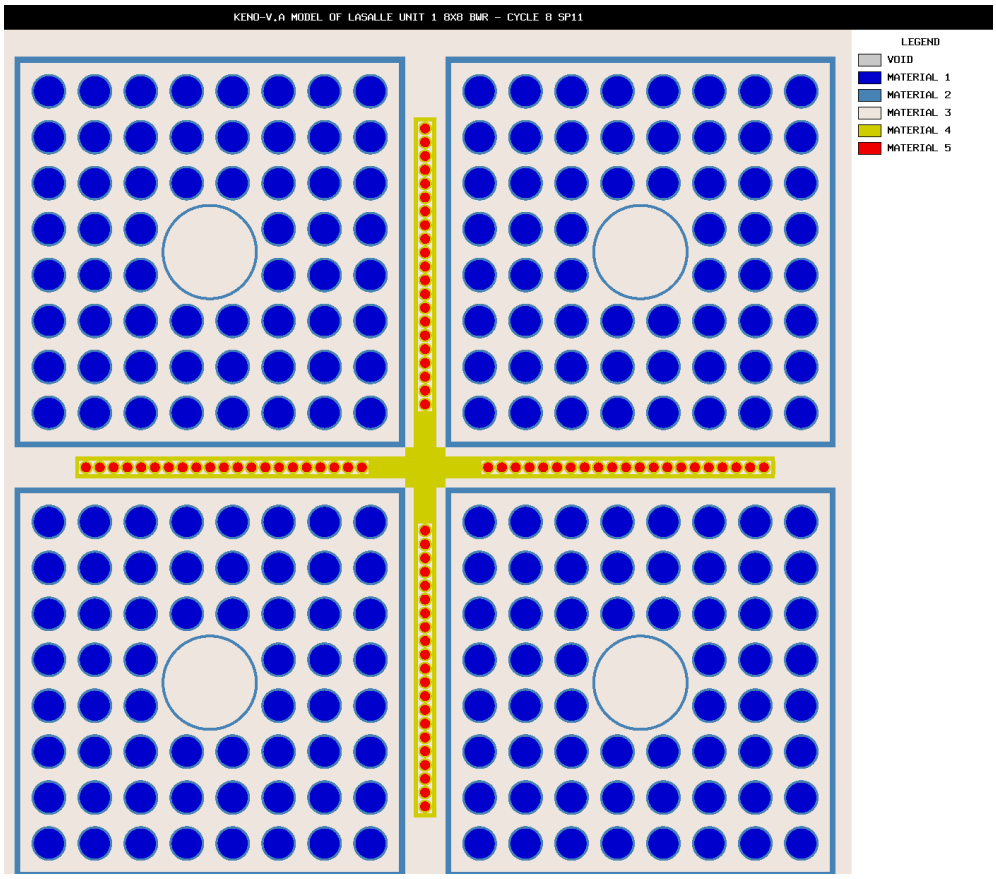


Fig. 13. KENO V.a model of LS1 assembly group and control blades.

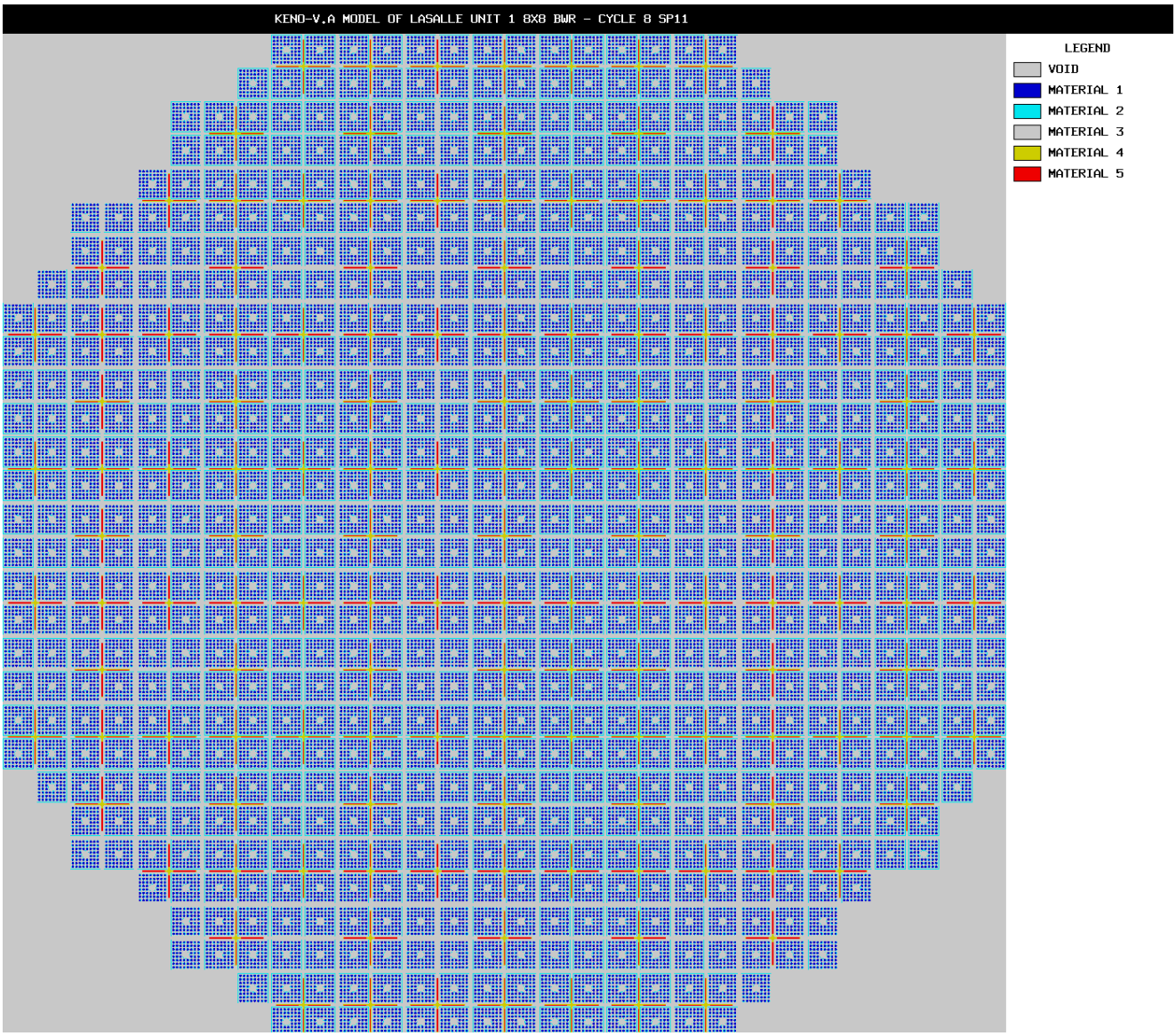


Fig. 14. KENO V.a model of the LS1 SP11 critical configuration.

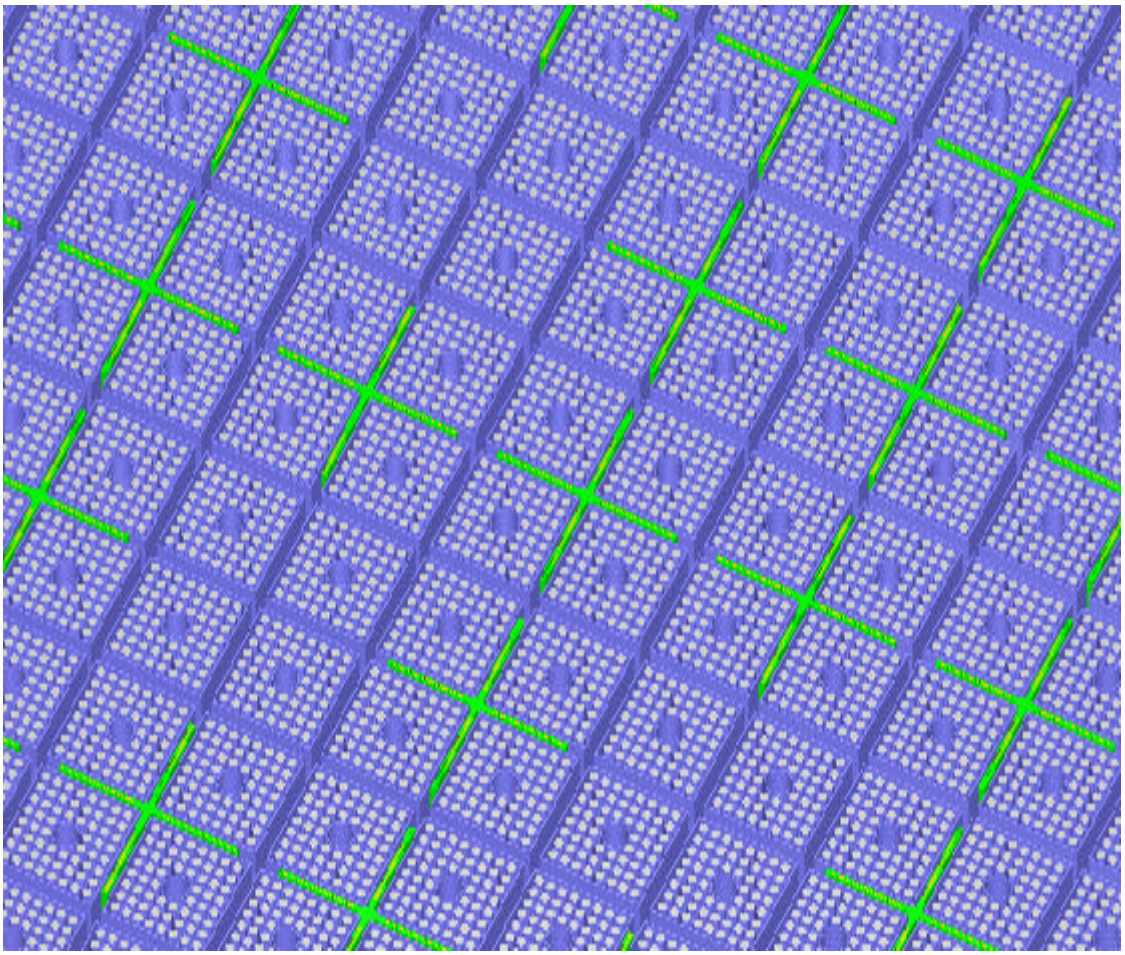


Fig. 15. KENO3D visualization of the LaSalle Unit 1 Reactor – top view.

4.8. SUMMARY OF KEY ANALYSIS APPROXIMATIONS

The key analysis assumptions and modeling approximations in the KENO V.a criticality analysis of the LS1 statepoints are summarized in this section. Since the fuel irradiated compositions were not calculated as part of this work, the approximations and uncertainties do not extend to the depletion analysis methodology. Only the assumptions in the criticality analysis are summarized here. The key modeling assumptions are the following:

1. all assemblies contain 60 pins for all axial zones (assembly mass conserved),
2. the gadolinium poison pins in the enriched uranium assemblies were approximated using a discrete symmetric 8-pin arrangement (see Fig. 12) in all assemblies, and also an homogenized (60-pin) arrangement,
3. uniform actinide and fission product concentrations in all assembly fuel zones (no correction for control blade or gadolinium poison perturbations on fuel compositions),
4. uniform oxygen (as ^{16}O) concentrations were assumed for all assemblies,
5. fuel assembly pin spacer grids and end region details were not modeled,
6. reactor core reflection was approximated by thick water reflection,
7. channel thickness for the assemblies H and J (see Table 3) were assumed to be the same as earlier cycles (assemblies A – K),
8. quarter-core (quasi eight-core) symmetry, and
9. ten axial burnup zones.

5. RESULTS AND DISCUSSION

The neutron multiplication factors (k_{eff}) calculated by KENO V.a for each of the five statepoint critical configurations are listed in Table 6. These results are compared against the known k_{eff} values.*

The KENO V.a results are based on 500 generations of 1000 particles per generation, for a total of 500,000 particle histories. The criticality analysis execution time was about 20 minutes CPU time on the DEC Alpha workstation.

The criticality calculations performed using the homogenized model for the gadolinium poison in the assemblies demonstrate that distributing the poison uniformly in all fuel pins results in a substantial underprediction in the system k_{eff} for most statepoints. The degree of underprediction is most pronounced in the Cycle 8 statepoints, which have a high initial gadolinium poison loading compared with the Cycle 7 statepoints, due to a larger number of fresh assemblies in the BOC core (248 compared to 208) and the higher gadolinium enrichment in the Cycle 8 fresh assemblies. The SP9 measurement, performed at a Cycle 7 burnup of about 8000 MWd/MTU, is accurately predicted by the homogeneous model likely due to the substantial depletion of the initial gadolinium poison loading in the core.

The criticality calculations performed using a heterogeneous symmetric 8-Gd-pin model resulted in a significant improvement in the predicted k_{eff}. For the middle-of-cycle (MOC) statepoints SP8 and SP9, the predicted k_{eff} value is within 1% $\Delta k/k$ of measurement. For the BOC and low-cycle-burnup statepoints SP7, SP10, and SP11, which will have the highest gadolinium poison concentrations, the KENO V.a results are overpredicting by between 1 and 2.3% $\Delta k/k$.

The discrete gadolinium poison pins were modeled using an 8-pin assembly approximation (Fig. 12) since the actual pin arrangement is proprietary information. The 8-pin configuration was easily implemented due to the assembly symmetry and the number of Gadolinium pins is close to the actual number of pins based on an average over the assemblies in the reactor core. If the average number of gadolinium poison pins is calculated based on the fresh assemblies in the BOC cores (where the majority of the gadolinium poison resides), then the effective average number of pins is estimated to be about 8.3 pins, based on the 208 fresh F- and G-type assemblies in Cycle 7, and about 9.1 pins per assembly based on the 248 fresh H- and J-type assemblies in Cycle 8. The use of 8 pins per assembly in the criticality analysis model, although close to the Cycle 7 average, is less than the average for the Cycle 8 statepoints, and may potentially result in an under-representation of the gadolinium worth in the assemblies.

A detailed assessment of the applicability of using an average number of poison pins to represent all assemblies in the core is beyond the scope of this report. In addition, this report has not addressed the effect of the poison pin arrangement in the assembly compared with the actual assembly arrangements because the assembly configurations are proprietary. Poison pins located

* Note that the actual k_{eff} for the statepoint is slightly greater than 1, as determined from the reactor period at the statepoint reactor configuration.

in the inner region of the assembly will have a different associated worth compared with pins located near the outer edge of the assembly. Similarly, the pin locations relative to the control blades may also be important.

An additional set of KENO V.a calculations were performed using a 9-pin gadolinium poison pin model, with the additional pin located in the outer ring of pins in the assembly. These calculations were performed for the Cycle 8 statepoints SP10 and SP11 only, because the average number of pins in the Cycle 7 assemblies was closer to 8 pins. The results are plotted in Fig. 16 with the previous results. The two Cycle 8 statepoints are substantially improved with the 9-pin assembly model. The k_{eff} values, which showed a 2% discrepancy using the 8-pin representation, are predicted to within about 1% using the 9-pin approximation, indicating a significant degree of sensitivity to the average number of poison pins associated with the assemblies.

Table 6. Calculated k_{eff} for LS1 statepoints

State point	Cycle	Cycle burnup (MWd/MTU)	Measured k_{eff}	Calculated k_{eff} (homogeneous Gd model)	Calculated k_{eff} (8-pin Gd model)	Calculated k_{eff} (9-pin Gd model – Cycle 8 only)
SP7	7 (BOC)	0.00	1.00584	0.9740 ± 0.0010	1.0163 ± 0.0009	[a]
SP8	7	4728.4	1.00519	0.9585 ± 0.0012	0.9992 ± 0.0010	[a]
SP9	7	7507.28	1.00875	1.0029 ± 0.0010	1.0110 ± 0.0009	[a]
SP10	8 (BOC)	0.00	1.00605	0.8972 ± 0.0010	1.0251 ± 0.0011	1.0154 ± 0.0009
SP11	8	89.8	1.00574	0.8978 ± 0.0011	1.0284 ± 0.0011	1.0175 ± 0.0009

[a] Values were not reported.

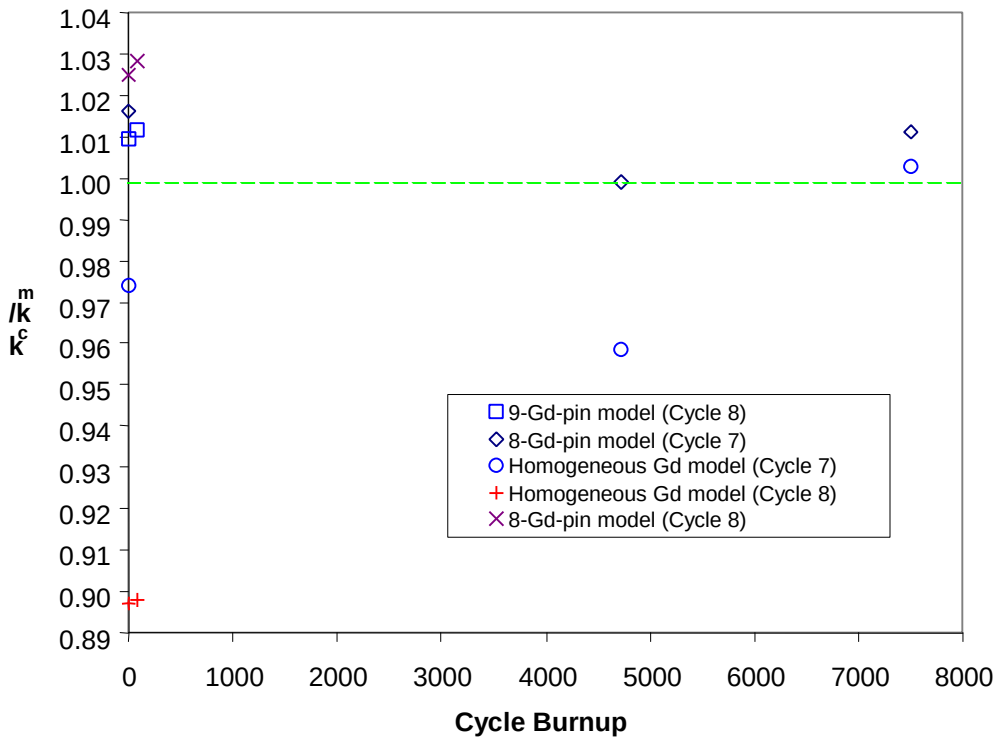


Fig. 16. Calculated (k_c)-to-measured (k_m) k_{eff} values vs cycle burnup.

6. CONCLUSIONS

The KENO V.a Monte Carlo results for five LS1 BWR critical configurations are within about 2% $\Delta k/k$ of the measured k_{eff} using a simplified assembly model that represents the gadolinium poison in a symmetric 8-pin arrangement. When the calculations for the Cycle 8 criticals are performed using a simplified 9-pin arrangement, a configuration closer to that of the fresh Cycle 8 assemblies, the results are improved to within approximately 1% for both reactor statepoints. These results suggest that the BWR CRCs can be predicted reasonably accurately without detailed information of the actual gadolinium pin distribution within the assemblies. More detailed calculations using the actual gadolinium pin distributions were not possible since the pin distributions for the assemblies in the LS1 CRCs were not available to ORNL for this work.

An homogenized representation of the gadolinium poison in the assembly generally results in a substantial underprediction in the k_{eff}. Uniformly distributing the gadolinium in all fuel pins gives the poison excessive weight in the calculations, due to the intermixing of poison in all fissile material regions and due to shelf-shielding effects. Only the SP9 configuration was well predicted with the homogeneous representation since the gadolinium poison is essentially depleted at the Cycle 7 burnup of about 8000 MWd/MTU, reducing the degree of heterogeneity in the assembly pin compositions.

Additional analyses are recommended to ensure that the approximations applied in these calculations have not significantly biased the results or produced offsetting biases. The sensitivity of the results to the average number of poison pins per assembly and the arrangement of the pins in the assemblies should be evaluated against a more detailed model that provides a closer representation of the actual assemblies (if this information is made available). It is also recommended that a sensitivity study of the key reactor state input parameters (e.g., moderator temperature and uniformity) be performed to determine the magnitude of state uncertainties on the results.

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APPENDIX A

CSASI INPUT LISTING FOR ASSEMBLY C14, ZONE 4, SP11

Appendix A

CSASI Input Listing for Assembly C14, Zone 4, SP11

```
=csasi
  C14                  4 Assy-04, Node-01 {Cyc-08,    .0 to Cyc-08,   3.7 EFPD}
44groupndf5  latticecell
gd-152     4 0  2.3018E-06 351. end
gd-154     4 0  2.5123E-05 351. end
gd-155     4 0  9.9843E-08 351. end
gd-156     4 0  5.3162E-04 351. end
gd-157     4 0  8.6781E-08 351. end
gd-158     4 0  6.5962E-04 351. end
gd-160     4 0  3.4941E-04 351. end
u-234      1 0  3.7129E-06 351. end
u-235      1 0  1.6175E-04 351. end
u-236      1 0  1.0197E-04 351. end
u-237      1 0  3.3743E-08 351. end
u-238      1 0  2.0949E-02 351. end
np-237     1 0  9.5084E-06 351. end
pu-238     1 0  3.6297E-06 351. end
pu-239     1 0  9.7283E-05 351. end
pu-240     1 0  5.3169E-05 351. end
pu-241     1 0  2.2941E-05 351. end
pu-242     1 0  1.2137E-05 351. end
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am-242m    1 0  2.7028E-08 351. end
am-243     1 0  2.3768E-06 351. end
cm-242     1 0  1.6727E-07 351. end
cm-244     1 0  6.6359E-07 351. end
cm-245     1 0  2.1761E-08 351. end
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se-78      1 0  1.9176E-07 351. end
se-80      1 0  9.8112E-07 351. end
br-81      1 0  1.4383E-06 351. end
se-82      1 0  2.3087E-06 351. end
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rb-85      1 0  6.5916E-06 351. end
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```

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xe-132     1 0  4.7494E-05 351. end
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cs-133     1 0  5.0292E-05 351. end
xe-134     1 0  6.4837E-05 351. end
cs-134     1 0  3.3155E-06 351. end
ba-134     1 0  3.1682E-06 351. end
cs-135     1 0  1.5614E-05 351. end
ba-135     1 0  1.5541E-08 351. end
xe-136     1 0  9.6732E-05 351. end
ba-136     1 0  6.9509E-07 351. end
cs-137     1 0  5.0625E-05 351. end
ba-137     1 0  3.4231E-06 351. end
ba-138     1 0  5.3836E-05 351. end
la-139     1 0  5.0252E-05 351. end
ba-140     1 0  1.0754E-07 351. end
la-140     1 0  1.5144E-08 351. end
ce-140     1 0  5.1127E-05 351. end
ce-141     1 0  1.9956E-07 351. end
pr-141     1 0  4.5163E-05 351. end
ce-142     1 0  4.5888E-05 351. end
nd-142     1 0  8.7430E-07 351. end
pr-143     1 0  9.8729E-08 351. end
nd-143     1 0  3.0896E-05 351. end
ce-144     1 0  5.3135E-06 351. end
nd-144     1 0  4.9021E-05 351. end
nd-145     1 0  2.6895E-05 351. end
nd-146     1 0  2.7556E-05 351. end
nd-147     1 0  3.7611E-08 351. end
pm-147     1 0  5.2387E-06 351. end
```

```
sm-147     1 0  4.9700E-06 351. end
nd-148     1 0  1.4226E-05 351. end
pm-148m    1 0  1.4943E-08 351. end
sm-148     1 0  4.9865E-06 351. end
sm-149     1 0  5.6819E-08 351. end
nd-150     1 0  6.7629E-06 351. end
sm-150     1 0  1.0844E-05 351. end
sm-151     1 0  4.2172E-07 351. end
sm-152     1 0  5.0339E-06 351. end
eu-153     1 0  4.3395E-06 351. end
sm-154     1 0  1.3255E-06 351. end
eu-154     1 0  7.1001E-07 351. end
gd-154     1 0  1.3126E-07 351. end
eu-155     1 0  1.8950E-07 351. end
eu-156     1 0  1.7562E-08 351. end
gd-156     1 0  2.9270E-06 351. end
gd-158     1 0  5.8893E-07 351. end
tb-159     1 0  7.6841E-08 351. end
gd-160     1 0  3.4864E-08 351. end
dy-161     1 0  1.0486E-08 351. end
o-16       1 0  4.5497E-02 351. end
arbm-zirc4 6.56 5 0 0 0 8016 0.12 24000 0.10 26000 0.20 50000 1.40
           40000 98.18 2 1.0 620.0 end
arbm-modr  0.9723            2   0   0   0
           1000     11.1900
           8016     88.81000
           3 1.0  560.3   end
end comp
squarepitch   1.62560   1.0642   1   3   1.2268   2  end
more data
res=4 cylinder  0.532 dan(4)=0.020  end
end
=wax
0$$ 41 e  1$$ 1 1t
2$$ 40 0 2t
end
=wax
0$$ 40 e  1$$ 2 1t
2$$ 41 0 2t
2$$  2 2 2t
3$$  1  4
4$$  9031404 8031404  3t
end
```

APPENDIX B

GECKO FORTRAN UTILITY CODE LISTING

Appendix B

GECKO Fortran Utility Code Listing

```
      program gecko2
c     ****************************************************************
c     gecko2 - get compositions for keno from origen
c     utility code to read the origen formatted output file from sas2h
c     printed nuclide compositions are available in a standard
c     composition input form suitable for inclusion in a csas
c     case i.e., kenova
c     ****************************************************************
      integer id(29)
      integer id19(600),id30(600)
      integer nucl(600)
      dimension nucid(2000),conc(2000),iprt(2000),aden(2000)
      dimension iz(2000),xa(2000)
      character*4 el(2000)
      character*1 sta(2000)
      character*3 mwt(2000)
      dimension lib(3)
      character*10 scid(600),hend*4
      character*4 blank*3,buf*132,dash*1,title*132,buf6*6,celparm*80
      character*4 totl,buf4,keywrd(4)
      data dash,blank,totl /'-','   ','tota'/
      data keywrd /'modu','npin','fuel','squa'/
      character*29 units
      data units /'nuclide concentrations, grams'/
c
c
c     read in acceptable nuclides for csas from standard composition lib
      open(20,file='stdcmp',status='old')
      open(5,status='unknown',form='formatted')
      open(99,file='record',form='formatted',position='append')
c
      isc=0
      mx1=1
      mx2=4
      ivf=0
      temp=351.
      hend=' end'
c
      do 12 i=1,600
        read(20,end=20,fmt='(a10,i12)') scid(isc+1),nucl(isc+1)
c       write(6,*) scid,nucl
        isc=isc+1
   12 continue
   20 continue
c     write(6,*) 'standard composition nuclides=',isc
c     print total number of nuclides in list
c
      open(83,status='old',form='unformatted',file='ft83f001')
      read(83) d1,nnuc,ngn,d2,d3,ngg
      if (ngn.ne.44) write(6,*) ' --- error --- ngn ne 44'
      if (nnuc.gt.600) write(6,*) ' --- error --- nnuc gt dim'
      ng=ngg+ngn
      do 30 i=1,nnuc
        read(83) id,ft30
        id19(i)=id(19)
        id30(i)=nint(ft30)*10
        mz=id19(i)/1000
        mass=(id19(i)-mz*1000)
        if (mass.gt.600) id30(i)=id30(i)+1
c       write(6,*) id19(i),mass,id30(i)
   30 continue
c
c *** start reading composition interface
```

```
c
      npois = 0
      j = 1
      k = 0
      do
      read(5,10000,end=120) buf
      if (buf(5:8).eq.keywrd(1)) then
          read(5,10000,end=120) buf
          title = buf(5:100)
          goto 10
      endif
      end do
c
   10 continue
      do
      read(5,10000,end=120) buf
      if (index(buf,keywrd(4)).gt.0) then
          loc = index(buf,keywrd(4))
          loc = loc + 24
          buf6 = buf(loc:loc+5)
c         write(6,*) 'fuelod=',buf6
          read(buf6,'(f6.3)') fd
          celparm(1:72)=buf(7:78)
          goto 18
      endif
      end do
c
   18 continue
      do
      read(5,10000,end=120) buf
      if (index(buf,keywrd(2)).gt.0) then
          loc1 = index(buf,keywrd(2))
          loc1 = loc1 + 14
          buf4 = buf(loc1:loc1+2)
c         write(6,*) 'npin/assembly=',buf4
          read(buf4,'(i3)') npin
          loc2 = index(buf,keywrd(3))
          if (loc2.eq.0) goto 100
          loc2 = loc2 + 9
          buf6 = buf(loc2:loc2+5)
c         write(6,*) 'fuelength=',buf6
          read(buf6,'(f6.3)') fuelngth
          goto 40
      endif
      end do
      write(6,*) ' --- error --- keywords not found'
      go to 100
c
   40   read(5,10000,end=120) buf
        ip = index(buf,units)
        if (ip.gt.0) then
c         start of nuclide concentrations
          read(5,10000,end=120) buf
          read(5,10000,end=120) buf
   42     read(5,10100,end=120) el(j),mwt(j),sta(j),xz,xa(j)
          if (el(j).eq.totl) then
c           write(6,*) 'match for total'
            k = k + 1
            lib(k) = j
            if (k.eq.3) goto 120
            go to 40
          endif
          if (el(j).eq.blank) then
            read(5,10000,end=120) buf
            read(5,10000,end=120) buf
            read(5,10000,end=120) buf
            read(5,10000,end=120) buf
            read(5,10000,end=120) buf
            go to 42
          endif
c         write(6,*) j,el(j),mwt(j),sta(j),xz,xa(j)
          read(mwt(j),'(i3)') iz(j)
```

```
          j = j + 1
          goto 42
        endif
      go to 40
c
  120 continue
c
      do 122 i=1,3
  122 lib(i)=lib(i) - 1
c
       iend = lib(3)
       afuel = (fd/2.)*(fd/2.)*3.141593
c      set vol below based on npin=60 to conserve mass per assy
       apin = 60.0
       vol = afuel*apin*fuelngth
c
c      prepare csas1x case input
       write(6,10300) title
       do 70 i=1,iend
         call noah(ia,el(i))
         idn = ia*10000+iz(i)*10
         if (sta(i).eq.'m') idn = idn + 1
c        write(6,*) el(i),mwt(i),sta(i),idn
c
c        check for lite element gd and eu
         ipois = 0
         if (i.gt.lib(1)) goto 48
         if (ia.eq.64) ipois=1
         if (ia.eq.63) ipois=1
         if (ipois.eq.0) go to 70
c        above rejects all non-poison lite elements
c
   48    continue
c        check that nuclid is on master library
         do 80 j=1,nnuc
           if (idn.ne.id30(j)) goto 80
           kd19 = id19(j)
c          set standard composition name scid
             do 50 k=1,isc
             if (kd19.eq.nucl(k)) goto 55
   50        continue
c          write(6,*) '--- no match on scid name for ',kd19
           go to 70
c
   55      continue
           vf = 1.
           if (ipois.eq.1) vf=8.0/apin
c          scale factor for number densities of poison pins (8)
           aden(i)=xa(i)*0.60225/iz(i)/vol/vf
           if (aden(i).lt.1.0e-8) goto 70
           if (ipois.eq.1) then
             write(6,85) scid(k),mx2,ivf,aden(i),temp,hend
             npois = npois + 1
           else
             write(6,85) scid(k),mx1,ivf,aden(i),temp,hend
           endif
c          above, allows simulation of lite element poisons if required
           goto 70
   80    continue
c        write(6,*) '--- following nuclide rejected ',idn
   70  continue
c
       aden2 = 4.5497e-2
       write(6,85) scid(195),mx1,ivf,aden2,temp,hend
c      above, write stdcmp for oxygen in fuel
c
c      always write trace amount of gd to ensure mix 4 is present
       if (npois.eq.0) write(6,85) 'gd-156    ',mx2,ivf,1e-20,temp,hend
c
       write(6,10600)
       write(6,10700)
       write(6,10400)
```

```
       write(6,10200) celparm
       write(6,10800) mx2,fd/2.0,mx2
       write(6,10500)
c      write(6,*) title
c      write(6,*) 'litel=',lib(1),'act=',lib(2),'fp=',lib(3)
c      write(6,*) 'fuelod=',fd
c      write(6,*) 'npin/assembly=',npin
c      write(6,*) 'fuelength=',fuelngth
c      write(6,*) 'fuel volume=',vol
c
       call wax(title,ice)
       write(99,12000) title(1:10),ice,npin,fd,fuelngth
c
   85  format(a10,2i2,1pe12.4,0pf5.0,a4)
   86  format(2i6,i10,3x,a10,1pe12.4)
      close (83)
      close (20)
  100 stop
10000 format(a132)
10100 format(3x,a4,a3,a1,1x,e9.2,50x,1x,e9.2)
10200 format(a72)
10300 format(7h=csasi ,/,a80,/,24h44groupndf5  latticecell)
10400 format(8hend comp)
10500 format(3hend)
10600 format(67harbm-zirc4 6.56 5 0 0 0 8016 0.12 24000 0.10
     & 26000 0.20 50000 1.40   /,11x,27h40000 98.18 2 1.0 620.0 end )
10700 format(43harbm-modr  0.9723            2   0   0   0  /
     & 11x,19h1000     11.1900    /
     & 11x,19h8016     88.81000   /
     & 11x,19h3 1.0  560.3   end  )
10800 format(10hmore data /
     & 4hres=,i1,10h cylinder ,f6.3,5h dan(,i1,12h)=0.020  end )
12000 format(6h asmby,a10,5h ice=,i7,6h npin=,i2,4h fd=,
     & f6.3,4h fl=,f6.3)
       end
c
      subroutine noah(i,name)
      character name*4,nel*2
      character*2 ele(99),sta(2)
c
      data ele/  ' h','he','li','be',' b',' c',' n',' o',' f','ne',
     * 'na','mg','al','si',' p',' s','cl','ar',' k','ca','sc','ti',' v',
     * 'cr','mn','fe','co','ni','cu','zn','ga','ge','as','se','br','kr',
     * 'rb','sr',' y','zr','nb','mo','tc','ru','rh','pd','ag','cd','in',
     * 'sn','sb','te',' i','xe','cs','ba','la','ce','pr','nd','pm','sm',
     * 'eu','gd','tb','dy','ho','er','tm','yb','lu','hf','ta',' w','re',
     * 'os','ir','pt','au','hg','tl','pb','bi','po','at','rn','fr','ra',
     * 'ac','th','pa',' u','np','pu','am','cm','bk','cf','es'/
      data sta/'  ','m '/
c
      nel = name(3:4)
      do 20 i=1,99
      if (nel.eq.ele(i)) return
   20 continue
      write(6,*) 'no match for nuclide',name
      stop
      end
c
      subroutine wax(title,id)
      character*132 title
      character*1 buf,dash,blank,name(10)
      data name /'A','B','C','D','E','F','G','H','I','J'/
      data blank,dash /' ','-'/
c
      buf = blank
      i = 0
      do while(buf.eq.blank)
        i = i + 1
        buf = title(i:i)
      end do
      do 20 j=1,10
        if (buf.eq.name(j)) goto 40
```

```
   20 continue
      write(6,*) ' --- error --- invalid name ',buf
      stop
   40 id = j*10000
      i = i + 1
      read(title(i:i),'(i1)') n1
      i = i + 1
      buf = title(i:i)
      if (buf.eq.dash) then
        nas = n1
      else if (buf.eq.blank) then
        nas = n1
      else
        read(buf,'(i1)') n2
        nas = n1*10 + n2
      endif
      i = i + 10
      buf = blank
      do while(buf.eq.blank)
        i = i + 1
        buf = title(i:i)
      end do
      read(title(i:i+1),'(i2)') node
      id = id + nas*100 + node
      id1 = id + 9000000
      id2 = id + 8000000
c
      write(6,'(4h=wax)')
      write(6,'(20h0$$ 41 e  1$$ 1 1t  )')
      write(6,'(20h2$$ 40 0 2t         )')
      write(6,'(3hend)')
      write(6,'(4h=wax)')
      write(6,'(20h0$$ 40 e  1$$ 2 1t  )')
      write(6,'(20h2$$ 41 0 2t         )')
      write(6,'(20h2$$  2 2 2t         )')
      write(6,'(10h3$$  1  4 )')
      write(6,'(4h4$$ ,2(i8), 4h  3t )') id1,id2
      write(6,'(3hend)')
      return
      end
```

APPENDIX C

LS1K FORTRAN UTILITY CODE LISTING AND ASSEMBLY MAP

Appendix C

LS1K Fortran Utility Code Listing and Assembly Map

```
      program ls1k
c     ****************************************************************
c     builds kenova material, geometry, and array data blocks, and
c     script files to generate material cross sections for the
c     lasalle unit 1 crc calculations
c     ****************************************************************
      character*1 blank,buf*20
      character*5 map(15,15)
      dimension imap(15,15),imap2(30,30)
      dimension imapf(59,59)
      dimension hz(10)
      data hz /15.24,45.72,60.96,5*45.72,2*15.24/
c     above, sets node heights
      common /mesage/ iboc,ncyc
      node = 10
      imax = 15
      jmax = 15
c
      read(5,'(a20)') buf
      write(6,*) 'preparing kenova data for ',buf(2:20)
      read(5,'(15a5)') ((map(i,j),i=1,imax),j=1,jmax)
      open(10,file='mixt',status='unknown',form='formatted')
      open(11,file='geom',status='unknown',form='formatted')
      open(12,file='array',status='unknown',form='formatted')
      write(10,'(10hread mixt  )')
      write(11,'(10hread geom  )')
      write(12,'(10hread array )')
      icnt = 0
      nu = 0
      iarr = 0
c --- reserve initial 9 mixes for structural and non-fuel matls
      mix = 8
c --- set special mixt assignments for boc statepoints
      iboc = 0
      if (index(buf,'boc').gt.0) then
        iboc = 1
        j = index(buf,'cycle')
        if (j.eq.0) stop
        j = j + 5
        blank = buf(j:j)
        read(blank,'(i1)') ncyc
      endif
c
      aden = 1.
c     above, aden set for macroscopic xsc
      do 20 j=1,jmax
      do 40 i=1,imax
      do 60 n=1,node
c       write(6,'(2x,a5)') map(i,j)(3:4)
        if (index(map(i,j),'X').gt.0) goto 40
c       above, skip symmetric sites
        icnt = icnt + 1
        nu = nu + 1
c       two mixtures per zone
        mix = mix + 2
c       determine xsec id from assembly name
        call label(map(i,j),idxs)
        write(6,*) idxs
        idxs = idxs + n
c       identifiers for u and u/gd pins
        idx1 = idxs + 9000000
        idx2 = idxs + 8000000
c --- write mixt file entry for mix/xsc map
```

```
        write(10,10000) mix,idx1,aden
        write(10,10400) mix+1,idx1,aden,idx2,aden
c
c --- write geometry data for each unit (nu)
        hzn = hz(n)
        write(11,10300) map(i,j),n,i+15,j+15,idxs
        write(11,10200) nu
        write(11,10500) mix,hzn,hzn,hzn
        nu1 = nu
c --- u pin complete
        nu = nu + 1
        write(11,10200) nu
        write(11,10500) mix+1,hzn,hzn,hzn
        nu1p = nu
c --- u+gd pin complete
        nu = nu + 1
        write(11,10200) nu
        write(11,10510) mix,hzn,hzn
        nu2 = nu
c --- u "hole" inner pin complete
        nu = nu + 1
        write(11,10200) nu
        write(11,10520) hzn,hzn,hzn,(nu2,k=1,12)
        nu3 = nu
c --- water rod plus inner u pins complete
        nu = nu + 1
        iarr = iarr + 1
        write(11,10200) nu
        write(11,10530) iarr
        write(12,13000) iarr,(nu1,k=1,4)
        nu4 = nu
c --- assembly corners (4x4) complete
        nu = nu + 1
        iarr = iarr + 1
        write(11,10200) nu
        write(11,10530) iarr
        write(12,13010) iarr,nu1,nu1p,(nu1,k=1,4),nu1,nu1p
        nu5 = nu
c --- assembly left side complete
        nu = nu + 1
        iarr = iarr + 1
        write(11,10200) nu
        write(11,10530) iarr
        write(12,13010) iarr,nu1p,(nu1,k=1,5),nu1p,nu1
        nu6 = nu
c --- assembly right side complete
        nu = nu + 1
        iarr = iarr + 1
        write(11,10200) nu
        write(11,10530) iarr
        write(12,13012) iarr,nu1p,nu1,nu1,nu1p,(nu1,k=1,4)
        nu7 = nu
c --- assembly bottom side complete
        nu = nu + 1
        iarr = iarr + 1
        write(11,10200) nu
        write(11,10530) iarr
        write(12,13012) iarr,(nu1,k=1,4),nu1p,nu1,nu1,nu1p
        nu8 = nu
c --- assembly top side complete
c
c --- now, define general assembly
        nu = nu + 1
        iarr = iarr + 1
        write(11,10200) nu
        write(11,10540) iarr,hzn,hzn
        write(12,13020) iarr,nu4,nu8,nu4,nu5,nu3,nu6,nu4,nu7,nu4
c
   60 continue
c --- all nodes complete, add assembly array (10 units per node)
       iarr = iarr + 1
       ilast = nu
```

```
      write(12,13040) iarr,(ilast-10*(k-1),k=10,1,-1)
      nu = nu + 1
      write(11,10200) nu
      write(11,10530) iarr
c --- store assembly node unit number in array imap to build core array
      imap(i,j) = nu
c
   40 continue
   20 continue
c --- fill symetric assembly sites (set as zero in imap)
      do 80 j=1,jmax
      do 90 i=1,imax
      if (imap(i,j).eq.0) imap(i,j)=imap(j,i)
      if (imap(i,j).eq.0) imap(i,j)=13000
   90 continue
   80 continue
c
      icnt = icnt/node
      write(6,*) icnt,' assemblies completed'
      write(6,*) 'core map   imap(i,j)'
      write(6,'(15a5)') ((map(i,j),i=1,15),j=1,15)
      write(6,'(15i5)') ((imap(i,j),i=1,15),j=1,15)
c
c --- generate core layout using array imap
      write(12,13100)
      nu = 9000
      write(12,13120) nu
c
c
c --- fill interstitial assembly locations with water units
      do 120 j=1,jmax*2
      do 140 i=1,imax*2
        ixe = 0
        iye = 0
c       test for x,y even,odd
        if (mod(i,2).eq.0) ixe = 1
        if (mod(j,2).eq.0) iye = 1
        if (ixe.eq.0) then
          if (iye.eq.0) imap2(i,j) = 13003
          if (iye.eq.1) imap2(i,j) = 13001
        else
          if (iye.eq.0) imap2(i,j) = 13002
          if (iye.eq.1) imap2(i,j) = imap(i/2,j/2)
        endif
c
c       even/even locations are assemblies
c
  140 continue
  120 continue
c
c     set locations of inserted cruxiform centres on map
c     row 1 - alternate full insertion - imap2 id=90003
      j = 1
      do 200 i=1,30,8
  200 imap2(i,j) = 90003
c     add (42,31) blade site for cycle 7 only
      imap2(13,j) = 90003
c
c     row 5 - full insertion all sites
      j = 5
      do 220 i=1,30,4
  220 imap2(i,j) = 90003
c
c     row 9 - alternate full insertion
      j = 9
      do 240 i=1,30,8
  240 imap2(i,j) = 90003
      imap2(5,j) = 90003
c     add (50,23) blade site for cycle 7 only
      imap2(21,9) = 90003
c
c     row 13 - full insertion all sites
```

```
      j = 13
      do 260 i=1,30,4
  260 imap2(i,j) = 90003
c
c     row 17 - alternate full insertion
      j = 17
      do 280 i=1,26,8
  280 imap2(i,j) = 90003
c     add (42,15) blade site for cycle 7 only
      imap2(13,j) = 90003
c
c     row 21 - full insertion all sites
      j = 21
      do 290 i=1,22,4
  290 imap2(i,j) = 90003
c
c     row 25 - alternate full insertion
      j = 25
      do 300 i=1,18,8
  300 imap2(i,j) = 90003
c
c     row 29 - full insertion all sites
      j = 29
      do 310 i=1,15,4
  310 imap2(i,j) = 90003
c
c *** map image 1/4 core imap2 to full core image imapf
c
      do 400 i=30,59
      do 400 j=30,59
  400 imapf(i,j) = imap2(i-29,j-29)
c
c     reflect to lower left quadrant
      do 420 i=1,29
      do 420 j=30,59
  420 imapf(i,j) = imapf(60-i,j)
c
c     now reflect to upper half core from lower half
      do 440 i=1,59
      do 440 j=1,29
  440 imapf(i,j) = imapf(i,60-j)
c
c *** add/modify locations for any non-symetric blade sites
      isp = 7
      if (isp.eq.10 .or. isp.eq.11) then
c       withdraw control rod at blade site (26,39)
        imapf(26,22) = 13003
c       set critical control absorber height (26,23)
        imapf(26,38) = 100001
      else if (isp.eq.9) then
c       set critical control absorber at site (34,7)
        imapf(34,54) = 100001
      else if (isp.eq.8) then
c       set critical control absorber at site (18,47) cycle 7 sp8 only
        imapf(18,14) = 100001
      else if (isp.eq.7) then
c       set critical control absorber at site (18,47) cycle 7 sp7 only
        imapf(34,6) = 100001
c       add control rod at blade site (34,7)
        imapf(34,54) = 90003
      else
        write(6,*) '--- error --- invalid statepoint ',isp
      endif
c
c *** now complete mapping of control blades
      lim = 59
      do 160 j=1,lim
      do 180 i=1,lim
      if (imapf(i,j).lt.90000) go to 180
c
      if (imapf(i,j).eq.90003) then
c ---   control rod 9C
```

```
        if (i.gt.1) imapf(i-1,j) = 13011
        if (i.lt.lim) imapf(i+1,j) = 13012
        if (j.gt.1) imapf(i,j-1) = 13009
        if (j.lt.lim) imapf(i,j+1) = 13010
        imapf(i,j) = 13013
      elseif (imapf(i,j).eq.100001) then
c ---   control rod 10A
        if (i.gt.1) imapf(i-1,j) = 13024
        if (i.lt.lim) imapf(i+1,j) = 13025
        if (j.gt.1) imapf(i,j-1) = 13022
        if (j.lt.lim) imapf(i,j+1) = 13023
        imapf(i,j) = 13026
      else
        write(6,*) 'invalid control rod id',imapf(i,j)
        stop
      endif
c
  180 continue
  160 continue
c
  800 continue
c --- print array data for complete core
      write(12,'(10i6)') ((imapf(i,j),i=1,59),j=1,59)
      write(12,'(10h end fill  )')
      write(14,'(59i6)') ((imapf(i,j),i=1,59),j=1,59)
      close(10)
      close(11)
      close(12)
      stop
10000 format(4hmix= ,i4,4h    ,i8,f5.1)
10100 format(10hread geom  )
10110 format(10hend geom   )
10200 format(4hunit,i6 )
10300 format(1h'/ 17h'--- uo2-gd pin  , a5,6h node=,i2,
     1 9h (site i= ,i2,4h, j=,i2,7h)  xsc=,i7 )
10400 format(4hmix= ,i4,4h    ,2(i8,f5.1))
10500 format(
     1 1x,'cylinder ',i4,' 1  0.5321   ',f5.2,'  0.0'/
     2 1x,'cylinder  2 1    0.6134   ',f5.2,'  0.0'/
     3 1x,'cuboid    3 1  4p0.8128   ',f5.2,'  0.0' )
10510 format(
     1 1x,'cylinder ',i4,' 1  0.5321   ',f5.2,'  0.0'/
     2 1x,'cylinder  2 1    0.6134   ',f5.2,'  0.0' )
10520 format(
     1 1x,'cylinder  3 1  1.6002     ',f5.2,'  0.0'/
     2 1x,'cylinder  2 1  1.7018     ',f5.2,'  0.0'/
     3 1x,'cuboid    3 1  4p3.2512   ',f5.2,'  0.0'/
     4 1x,'hole ',i5,'    2.4384  2.4384  0.0'/
     5 1x,'hole ',i5,'    2.4384  0.8128  0.0'/
     6 1x,'hole ',i5,'    2.4384 -0.8128  0.0'/
     7 1x,'hole ',i5,'    2.4384 -2.4384  0.0'/
     8 1x,'hole ',i5,'    0.8128 -2.4384  0.0'/
     9 1x,'hole ',i5,'   -0.8128 -2.4384  0.0'/
     a 1x,'hole ',i5,'   -2.4384 -2.4384  0.0'/
     b 1x,'hole ',i5,'   -2.4384 -0.8128  0.0'/
     c 1x,'hole ',i5,'   -2.4384  0.8128  0.0'/
     d 1x,'hole ',i5,'   -2.4384  2.4384  0.0'/
     e 1x,'hole ',i5,'   -0.8128  2.4384  0.0'/
     f 1x,'hole ',i5,'    0.8128  2.4384  0.0'  )
10530 format(
     1 1x,'array ',i4,'   3*0' )
10540 format(
     1 1x,'array ',i4,'    -6.5024 -6.5024  0.0'/
     2 1x,'cuboid   3 1  4p6.7031  ',f5.2,'  0.0'/
     3 1x,'cuboid   2 1  4p6.9061  ',f5.2,'  0.0' )
13000 format(
     1 4hara= ,i4,27h  nux=2  nuy=2  nuz=1 fill /
     2 4i6,12h   end fill  )
13010 format(
     1 4hara= ,i4,27h  nux=2  nuy=4  nuz=1 fill /
     2 8i6,12h   end fill  )
13012 format(
```

```
     1 4hara= ,i4,27h  nux=4  nuy=2  nuz=1 fill /
     2 8i6,12h   end fill  )
13020 format(
     1 4hara= ,i4,27h  nux=3  nuy=3  nuz=1 fill /
     2 3i6/ 3i6/ 3i6 ,12h   end fill  )
13040 format(
     1 4hara= ,i4,27h  nux=1  nuy=1  nuz=10 fill /
     2 5i6/ 5i6 ,12h   end fill  )
13100 format(
     1 37h'--- reactor core array - layout map  )
13120 format(
     1 4hara= ,i4,27h  nux=59 nuy=59 nuz=1 fill )
      end
c
      subroutine label(asmby,idxs)
      character*5 asmby
      character*1 buf,blank,dash,name(10)
      data name /'A','B','C','D','E','F','G','H','I','J'/
      data blank,dash /' ','-'/
      common /mesage/ iboc,ncyc
      buf = blank
      i = 0
      do while(buf.eq.blank)
        i = i + 1
        buf = asmby(i:i)
      end do
      do 20 j=1,10
        if (buf.eq.name(j)) goto 40
   20 continue
      write(6,*) ' --- error --- invalid name ',buf
      stop
   40 idxs = j*10000
c --- if boc sp -
      if (iboc.eq.1) then
        if (ncyc.eq.7) then
          if (j.eq.6) return
          if (j.eq.7) return
        else if (ncyc.eq.8) then
          if (j.eq.8) return
          if (j.eq.10) return
        endif
      endif
c
      i = i + 1
      read(asmby(i:i),'(i1)') n1
      i = i + 1
      buf = asmby(i:i)
      if (buf.eq.dash) then
        m = n1
      else if (buf.eq.blank) then
        m = n1
      else
        read(buf,'(i1)') n2
        m = n1*10 + n2
      endif
      idxs = idxs + m*100
      return
      end
```

Cycle 8 Assembly Map

```
=cycle8
  D4  H18   F3  D13   E6   J5  F17   E9  D15  J11   F6   F2  D10   E5   C4
   X  D16   J6   G7  J12   F7   J4   F1  H10   E7  J10   H6   H7   E1   C5
 F10    X   F4   H9  G12   J8  F14   J9  G14  H16  F16  H12  F15   D7   C2
   X  G11    X  D12   D2  G15   J2   D3   E2   G5  H15   G9  D19  D21  C19
   X    X    X  D14   G1  J13   G6  D11   G3   J7   H1  D20   D6   D9  C29
   X    X    X    X    X  G10   H5   G4   J1   H2  C14  H11   F9   E8  C25
   X    X    X    X    X    X   D8   J3  H13   G2  H17   H3  G16   E3   C1
   X  F18    X   D5    X   G8    X  D18  D17   H8  H14   H4  E12  C26    X
   X    X    X   E4    X    X    X    X   D1  F11  G13   F5   C3    X    X
   X  E11    X    X    X    X    X    X    X  F13  C21  C27  C22    X    X
   X    X    X    X    X    X    X    X    X    X   C9    X    X    X    X
 F12    X    X    X    X    X    X    X   F8    X    X    X    X    X    X
   X    X    X    X    X    X    X    X  C12  C28    X    X    X    X    X
 E10    X    X    X    X    X    X    X    X    X    X    X    X    X    X
  C8    X    X  C17    X    X    X    X    X    X    X    X    X    X    X
end
```

APPENDIX D

ABRIDGED KENO V.A INPUT LISTING

FOR LS1 STATEPOINT CONFIGURATIONS

Appendix D

Abbreviated KENO V.a Input Listing for LS1 Statepoint Configurations

```
=kenova
keno-v.a model of lasalle unit 1 8x8 BWR - cycle 8 SP11
read parm
npg=1000 gen=503 nsk=5 nub=no fdn=no tme=120
xsc=14 lib=40
lng=2000000 nb8=9000
run=yes plt=no
end parm
read mixt
mix=2 2 1.
mix=3 3 1.
mix=4 4 1.
mix=5 5 1.
' start fuel mixt
mix=  10     9040401  1.0
mix=  11     9040401  1.0 8040401  1.0
mix=  12     9040402  1.0
mix=  13     9040402  1.0 8040402  1.0
mix=  14     9040403  1.0
mix=  15     9040403  1.0 8040403  1.0
mix=  16     9040404  1.0
mix=  17     9040404  1.0 8040404  1.0
mix=  18     9040405  1.0
mix=  19     9040405  1.0 8040405  1.0
mix=  20     9040406  1.0
mix=  21     9040406  1.0 8040406  1.0
   .
   .
   .


   (2309 lines deleted)


   .
   .
   .
mix=2329     9031710  1.0 8031710  1.0
end mixt
'
read geom
'
'--- uo2-gd pin    D4  node= 1 (site i=16, j=16)  xsc=  40401
unit     1
 cylinder   10 1  0.5321   15.24  0.0
 cylinder  2 1    0.6134   15.24  0.0
 cuboid    3 1  4p0.8128   15.24  0.0
unit     2
 cylinder   11 1  0.5321   15.24  0.0
 cylinder  2 1    0.6134   15.24  0.0
 cuboid    3 1  4p0.8128   15.24  0.0
unit     3
 cylinder   10 1  0.5321   15.24  0.0
 cylinder  2 1    0.6134   15.24  0.0
unit     4
 cylinder  3 1  1.6002     15.24  0.0
 cylinder  2 1  1.7018     15.24  0.0
 cuboid    3 1  4p3.2512   15.24  0.0
 hole     3    2.4384  2.4384  0.0
 hole     3    2.4384  0.8128  0.0
 hole     3    2.4384 -0.8128  0.0
```

```
 hole     3    2.4384 -2.4384  0.0
 hole     3    0.8128 -2.4384  0.0
 hole     3   -0.8128 -2.4384  0.0
 hole     3   -2.4384 -2.4384  0.0
 hole     3   -2.4384 -0.8128  0.0
 hole     3   -2.4384  0.8128  0.0
 hole     3   -2.4384  2.4384  0.0
 hole     3   -0.8128  2.4384  0.0
 hole     3    0.8128  2.4384  0.0
unit     5
 array    1   3*0
unit     6
 array    2   3*0
unit     7
 array    3   3*0
unit     8
 array    4   3*0
unit     9
 array    5   3*0
unit    10
 array    6    -6.5024 -6.5024  0.0
 cuboid   3 1  4p6.7031  15.24  0.0
 cuboid   2 1  4p6.9061  15.24  0.0
'
'--- uo2-gd pin    D4  node= 2 (site i=16, j=16)  xsc=  40402
unit    11
 cylinder   12 1  0.5321   45.72  0.0
 cylinder  2 1    0.6134   45.72  0.0
 cuboid    3 1  4p0.8128   45.72  0.0
unit    12
 cylinder   13 1  0.5321   45.72  0.0
 cylinder  2 1    0.6134   45.72  0.0
 cuboid    3 1  4p0.8128   45.72  0.0
unit    13
 cylinder   12 1  0.5321   45.72  0.0
 cylinder  2 1    0.6134   45.72  0.0
unit    14
 cylinder  3 1  1.6002     45.72  0.0
 cylinder  2 1  1.7018     45.72  0.0
 cuboid    3 1  4p3.2512   45.72  0.0
 hole    13    2.4384  2.4384  0.0
 hole    13    2.4384  0.8128  0.0
 hole    13    2.4384 -0.8128  0.0
 hole    13    2.4384 -2.4384  0.0
 hole    13    0.8128 -2.4384  0.0
 hole    13   -0.8128 -2.4384  0.0
 hole    13   -2.4384 -2.4384  0.0
 hole    13   -2.4384 -0.8128  0.0
 hole    13   -2.4384  0.8128  0.0
 hole    13   -2.4384  2.4384  0.0
 hole    13   -0.8128  2.4384  0.0
 hole    13    0.8128  2.4384  0.0
unit    15
 array    7   3*0
unit    16
 array    8   3*0
unit    17
 array    9   3*0
unit    18
 array   10   3*0
unit    19
 array   11   3*0
unit    20
 array   12    -6.5024 -6.5024  0.0
 cuboid   3 1  4p6.7031  45.72  0.0
 cuboid   2 1  4p6.9061  45.72  0.0
'
'--- uo2-gd pin    D4  node= 3 (site i=16, j=16)  xsc=  40403
unit    21
 cylinder   14 1  0.5321   60.96  0.0
 cylinder  2 1    0.6134   60.96  0.0
 cuboid    3 1  4p0.8128   60.96  0.0
```

```
unit    22
 cylinder   15 1  0.5321   60.96  0.0
 cylinder  2 1    0.6134   60.96  0.0
 cuboid    3 1  4p0.8128   60.96  0.0
unit    23
 cylinder   14 1  0.5321   60.96  0.0
 cylinder  2 1    0.6134   60.96  0.0
unit    24
 cylinder  3 1  1.6002     60.96  0.0
 cylinder  2 1  1.7018     60.96  0.0
 cuboid    3 1  4p3.2512   60.96  0.0
 hole    23    2.4384  2.4384  0.0
 hole    23    2.4384  0.8128  0.0
 hole    23    2.4384 -0.8128  0.0
 hole    23    2.4384 -2.4384  0.0
 hole    23    0.8128 -2.4384  0.0
 hole    23   -0.8128 -2.4384  0.0
 hole    23   -2.4384 -2.4384  0.0
 hole    23   -2.4384 -0.8128  0.0
 hole    23   -2.4384  0.8128  0.0
 hole    23   -2.4384  2.4384  0.0
 hole    23   -0.8128  2.4384  0.0
 hole    23    0.8128  2.4384  0.0
unit    25
 array   13   3*0
unit    26
 array   14   3*0
unit    27
 array   15   3*0
unit    28
 array   16   3*0
unit    29
 array   17   3*0
unit    30
 array   18    -6.5024 -6.5024  0.0
 cuboid   3 1  4p6.7031  60.96  0.0
 cuboid   2 1  4p6.9061  60.96  0.0
'
'--- uo2-gd pin    D4  node= 4 (site i=16, j=16)  xsc=  40404
unit    31
 cylinder   16 1  0.5321   45.72  0.0
 cylinder  2 1    0.6134   45.72  0.0
 cuboid    3 1  4p0.8128   45.72  0.0
unit    32
 cylinder   17 1  0.5321   45.72  0.0
 cylinder  2 1    0.6134   45.72  0.0
 cuboid    3 1  4p0.8128   45.72  0.0
unit    33
 cylinder   16 1  0.5321   45.72  0.0
 cylinder  2 1    0.6134   45.72  0.0
unit    34
 cylinder  3 1  1.6002     45.72  0.0
 cylinder  2 1  1.7018     45.72  0.0
 cuboid    3 1  4p3.2512   45.72  0.0
 hole    33    2.4384  2.4384  0.0
 hole    33    2.4384  0.8128  0.0
 hole    33    2.4384 -0.8128  0.0
 hole    33    2.4384 -2.4384  0.0
 hole    33    0.8128 -2.4384  0.0
 hole    33   -0.8128 -2.4384  0.0
 hole    33   -2.4384 -2.4384  0.0
 hole    33   -2.4384 -0.8128  0.0
 hole    33   -2.4384  0.8128  0.0
 hole    33   -2.4384  2.4384  0.0
 hole    33   -0.8128  2.4384  0.0
 hole    33    0.8128  2.4384  0.0
unit    35
 array   19   3*0
unit    36
 array   20   3*0
unit    37
 array   21   3*0
```

```
unit    38
 array   22   3*0
unit    39
 array   23   3*0
unit    40
 array   24    -6.5024 -6.5024  0.0
 cuboid   3 1  4p6.7031  45.72  0.0
 cuboid   2 1  4p6.9061  45.72  0.0
'
'--- uo2-gd pin    D4  node= 5 (site i=16, j=16)  xsc=  40405
unit    41
 cylinder   18 1  0.5321   45.72  0.0
 cylinder  2 1    0.6134   45.72  0.0
 cuboid    3 1  4p0.8128   45.72  0.0
unit    42
 cylinder   19 1  0.5321   45.72  0.0
 cylinder  2 1    0.6134   45.72  0.0
 cuboid    3 1  4p0.8128   45.72  0.0
unit    43
 cylinder   18 1  0.5321   45.72  0.0
 cylinder  2 1    0.6134   45.72  0.0
unit    44
 cylinder  3 1  1.6002     45.72  0.0
 cylinder  2 1  1.7018     45.72  0.0
 cuboid    3 1  4p3.2512   45.72  0.0
 hole    43    2.4384  2.4384  0.0
 hole    43    2.4384  0.8128  0.0
 hole    43    2.4384 -0.8128  0.0
 hole    43    2.4384 -2.4384  0.0
 hole    43    0.8128 -2.4384  0.0
 hole    43   -0.8128 -2.4384  0.0
 hole    43   -2.4384 -2.4384  0.0
 hole    43   -2.4384 -0.8128  0.0
 hole    43   -2.4384  0.8128  0.0
 hole    43   -2.4384  2.4384  0.0
 hole    43   -0.8128  2.4384  0.0
 hole    43    0.8128  2.4384  0.0
unit    45
 array   25   3*0
unit    46
 array   26   3*0
unit    47
 array   27   3*0
unit    48
 array   28   3*0
unit    49
 array   29   3*0
unit    50
 array   30    -6.5024 -6.5024  0.0
 cuboid   3 1  4p6.7031  45.72  0.0
 cuboid   2 1  4p6.9061  45.72  0.0
'
'--- uo2-gd pin    D4  node= 6 (site i=16, j=16)  xsc=  40406
unit    51
 cylinder   20 1  0.5321   45.72  0.0
 cylinder  2 1    0.6134   45.72  0.0
 cuboid    3 1  4p0.8128   45.72  0.0
unit    52
 cylinder   21 1  0.5321   45.72  0.0
 cylinder  2 1    0.6134   45.72  0.0
 cuboid    3 1  4p0.8128   45.72  0.0
unit    53
 cylinder   20 1  0.5321   45.72  0.0
 cylinder  2 1    0.6134   45.72  0.0
unit    54
 cylinder  3 1  1.6002     45.72  0.0
 cylinder  2 1  1.7018     45.72  0.0
 cuboid    3 1  4p3.2512   45.72  0.0
 hole    53    2.4384  2.4384  0.0
 hole    53    2.4384  0.8128  0.0
 hole    53    2.4384 -0.8128  0.0
 hole    53    2.4384 -2.4384  0.0
```

```
 hole    53    0.8128 -2.4384  0.0
 hole    53   -0.8128 -2.4384  0.0
 hole    53   -2.4384 -2.4384  0.0
 hole    53   -2.4384 -0.8128  0.0
 hole    53   -2.4384  0.8128  0.0
 hole    53   -2.4384  2.4384  0.0
 hole    53   -0.8128  2.4384  0.0
 hole    53    0.8128  2.4384  0.0
unit    55
 array   31   3*0
unit    56
 array   32   3*0
unit    57
 array   33   3*0
unit    58
 array   34   3*0
unit    59
 array   35   3*0
unit    60
 array   36    -6.5024 -6.5024  0.0
 cuboid   3 1  4p6.7031  45.72  0.0
 cuboid   2 1  4p6.9061  45.72  0.0
'
'--- uo2-gd pin    D4  node= 7 (site i=16, j=16)  xsc=  40407
unit    61
 cylinder   22 1  0.5321   45.72  0.0
 cylinder  2 1    0.6134   45.72  0.0
 cuboid    3 1  4p0.8128   45.72  0.0
unit    62
 cylinder   23 1  0.5321   45.72  0.0
 cylinder  2 1    0.6134   45.72  0.0
 cuboid    3 1  4p0.8128   45.72  0.0
unit    63
 cylinder   22 1  0.5321   45.72  0.0
 cylinder  2 1    0.6134   45.72  0.0
unit    64
 cylinder  3 1  1.6002     45.72  0.0
 cylinder  2 1  1.7018     45.72  0.0
 cuboid    3 1  4p3.2512   45.72  0.0
 hole    63    2.4384  2.4384  0.0
 hole    63    2.4384  0.8128  0.0
 hole    63    2.4384 -0.8128  0.0
 hole    63    2.4384 -2.4384  0.0
 hole    63    0.8128 -2.4384  0.0
 hole    63   -0.8128 -2.4384  0.0
 hole    63   -2.4384 -2.4384  0.0
 hole    63   -2.4384 -0.8128  0.0
 hole    63   -2.4384  0.8128  0.0
 hole    63   -2.4384  2.4384  0.0
 hole    63   -0.8128  2.4384  0.0
 hole    63    0.8128  2.4384  0.0
unit    65
 array   37   3*0
unit    66
 array   38   3*0
unit    67
 array   39   3*0
unit    68
 array   40   3*0
unit    69
 array   41   3*0
unit    70
 array   42    -6.5024 -6.5024  0.0
 cuboid   3 1  4p6.7031  45.72  0.0
 cuboid   2 1  4p6.9061  45.72  0.0
'
'--- uo2-gd pin    D4  node= 8 (site i=16, j=16)  xsc=  40408
unit    71
 cylinder   24 1  0.5321   45.72  0.0
 cylinder  2 1    0.6134   45.72  0.0
 cuboid    3 1  4p0.8128   45.72  0.0
unit    72
```

```
 cylinder   25 1  0.5321   45.72  0.0
 cylinder  2 1    0.6134   45.72  0.0
 cuboid    3 1  4p0.8128   45.72  0.0
unit    73
 cylinder   24 1  0.5321   45.72  0.0
 cylinder  2 1    0.6134   45.72  0.0
unit    74
 cylinder  3 1  1.6002     45.72  0.0
 cylinder  2 1  1.7018     45.72  0.0
 cuboid    3 1  4p3.2512   45.72  0.0
 hole    73    2.4384  2.4384  0.0
 hole    73    2.4384  0.8128  0.0
 hole    73    2.4384 -0.8128  0.0
 hole    73    2.4384 -2.4384  0.0
 hole    73    0.8128 -2.4384  0.0
 hole    73   -0.8128 -2.4384  0.0
 hole    73   -2.4384 -2.4384  0.0
 hole    73   -2.4384 -0.8128  0.0
 hole    73   -2.4384  0.8128  0.0
 hole    73   -2.4384  2.4384  0.0
 hole    73   -0.8128  2.4384  0.0
 hole    73    0.8128  2.4384  0.0
unit    75
 array   43   3*0
unit    76
 array   44   3*0
unit    77
 array   45   3*0
unit    78
 array   46   3*0
unit    79
 array   47   3*0
unit    80
 array   48    -6.5024 -6.5024  0.0
 cuboid   3 1  4p6.7031  45.72  0.0
 cuboid   2 1  4p6.9061  45.72  0.0
'
'--- uo2-gd pin    D4  node= 9 (site i=16, j=16)  xsc=  40409
unit    81
 cylinder   26 1  0.5321   15.24  0.0
 cylinder  2 1    0.6134   15.24  0.0
 cuboid    3 1  4p0.8128   15.24  0.0
unit    82
 cylinder   27 1  0.5321   15.24  0.0
 cylinder  2 1    0.6134   15.24  0.0
 cuboid    3 1  4p0.8128   15.24  0.0
unit    83
 cylinder   26 1  0.5321   15.24  0.0
 cylinder  2 1    0.6134   15.24  0.0
unit    84
 cylinder  3 1  1.6002     15.24  0.0
 cylinder  2 1  1.7018     15.24  0.0
 cuboid    3 1  4p3.2512   15.24  0.0
 hole    83    2.4384  2.4384  0.0
 hole    83    2.4384  0.8128  0.0
 hole    83    2.4384 -0.8128  0.0
 hole    83    2.4384 -2.4384  0.0
 hole    83    0.8128 -2.4384  0.0
 hole    83   -0.8128 -2.4384  0.0
 hole    83   -2.4384 -2.4384  0.0
 hole    83   -2.4384 -0.8128  0.0
 hole    83   -2.4384  0.8128  0.0
 hole    83   -2.4384  2.4384  0.0
 hole    83   -0.8128  2.4384  0.0
 hole    83    0.8128  2.4384  0.0
unit    85
 array   49   3*0
unit    86
 array   50   3*0
unit    87
 array   51   3*0
unit    88
```

```
 array   52   3*0
unit    89
 array   53   3*0
unit    90
 array   54    -6.5024 -6.5024  0.0
 cuboid   3 1  4p6.7031  15.24  0.0
 cuboid   2 1  4p6.9061  15.24  0.0
'
'--- uo2-gd pin    D4  node=10 (site i=16, j=16)  xsc=  40410
unit    91
 cylinder   28 1  0.5321   15.24  0.0
 cylinder  2 1    0.6134   15.24  0.0
 cuboid    3 1  4p0.8128   15.24  0.0
unit    92
 cylinder   29 1  0.5321   15.24  0.0
 cylinder  2 1    0.6134   15.24  0.0
 cuboid    3 1  4p0.8128   15.24  0.0
unit    93
 cylinder   28 1  0.5321   15.24  0.0
 cylinder  2 1    0.6134   15.24  0.0
unit    94
 cylinder  3 1  1.6002     15.24  0.0
 cylinder  2 1  1.7018     15.24  0.0
 cuboid    3 1  4p3.2512   15.24  0.0
 hole    93    2.4384  2.4384  0.0
 hole    93    2.4384  0.8128  0.0
 hole    93    2.4384 -0.8128  0.0
 hole    93    2.4384 -2.4384  0.0
 hole    93    0.8128 -2.4384  0.0
 hole    93   -0.8128 -2.4384  0.0
 hole    93   -2.4384 -2.4384  0.0
 hole    93   -2.4384 -0.8128  0.0
 hole    93   -2.4384  0.8128  0.0
 hole    93   -2.4384  2.4384  0.0
 hole    93   -0.8128  2.4384  0.0
 hole    93    0.8128  2.4384  0.0
unit    95
 array   55   3*0
unit    96
 array   56   3*0
unit    97
 array   57   3*0
unit    98
 array   58   3*0
unit    99
 array   59   3*0
unit   100
 array   60    -6.5024 -6.5024  0.0
 cuboid   3 1  4p6.7031  15.24  0.0
 cuboid   2 1  4p6.9061  15.24  0.0
unit   101
 array   61   3*0
'
'--- uo2-gd pin   H18  node= 1 (site i=17, j=16)  xsc=  81801
unit   102
 cylinder   30 1  0.5321   15.24  0.0
 cylinder  2 1    0.6134   15.24  0.0
 cuboid    3 1  4p0.8128   15.24  0.0
unit   103
 cylinder   31 1  0.5321   15.24  0.0
 cylinder  2 1    0.6134   15.24  0.0
 cuboid    3 1  4p0.8128   15.24  0.0
unit   104
 cylinder   30 1  0.5321   15.24  0.0
 cylinder  2 1    0.6134   15.24  0.0
unit   105
 cylinder  3 1  1.6002     15.24  0.0
 cylinder  2 1  1.7018     15.24  0.0
 cuboid    3 1  4p3.2512   15.24  0.0
 hole   104    2.4384  2.4384  0.0
 hole   104    2.4384  0.8128  0.0
 hole   104    2.4384 -0.8128  0.0
```

```
 hole   104    2.4384 -2.4384  0.0
 hole   104    0.8128 -2.4384  0.0
 hole   104   -0.8128 -2.4384  0.0
 hole   104   -2.4384 -2.4384  0.0
 hole   104   -2.4384 -0.8128  0.0
 hole   104   -2.4384  0.8128  0.0
 hole   104   -2.4384  2.4384  0.0
 hole   104   -0.8128  2.4384  0.0
 hole   104    0.8128  2.4384  0.0
unit   106
 array   62   3*0
unit   107
 array   63   3*0
unit   108
 array   64   3*0
unit   109
 array   65   3*0
unit   110
 array   66   3*0
unit   111
 array   67    -6.5024 -6.5024  0.0
 cuboid   3 1  4p6.7031  15.24  0.0
 cuboid   2 1  4p6.9061  15.24  0.0
'
'
   .
   .
   .


   (49,636 lines deleted)


   .
   .
   .
   .
'-----------------------------------------------
'
unit 12000
'--- non-fuelled lattice sites
 cuboid 3 1  4p6.9061  381.0 0.0
'
'-----------inter-assembly water-----------------
unit 12001
'--- assembly interstitial water (top/bottom)
 cuboid 3 1  2p0.7139  2p6.9061  381.0 0.0
'
unit 12002
'--- assembly interstitial water (left/right)
 cuboid 3 1  2p6.9061  2p0.7139  381.0 0.0
'
unit 12003
'--- assembly interstitial water (intersection)
 cuboid 3 1  4p0.7139  381.0 0.0
'
'-----------------------------------------------
unit 12004
'--- b4c rod unit --- inserted control rod
 cylinder 5 1  0.1753    365.8  0.0
 cylinder 4 1  0.2388    365.8  0.0
 cuboid   3 1  4p0.244   365.8  0.0
'
unit 12005
'--- b4c rod unit --- critical control blade (20 notches)
 cylinder 5 1  0.1753    213.4  0.0
 cylinder 4 1  0.2388    213.4  0.0
 cuboid   3 1  4p0.244   213.4  0.0
'
'-----------inserted control blade---------------------
unit 12009
'--- control blade (top)
```

```
 array  8002     -0.244  -4.6203  0.0
 cuboid 4 1  2p0.3962  6.9060 -4.7625  365.8 0.0
 cuboid 3 1  2p0.7139  2p6.9061  381.0 0.0
'
unit 12010
'--- control blade (bottom)
 array  8002     -0.244  -5.6350  0.0
 cuboid 4 1  2p0.3962  4.7625 -6.9060  365.8 0.0
 cuboid 3 1  2p0.7139  2p6.9061  381.0 0.0
'
unit 12011
'--- control blade (left)
 array  8001   -4.6203 -0.244     0.0
 cuboid 4 1  6.9060 -4.7625  2p0.3962  365.8 0.0
 cuboid 3 1  2p6.9061  2p0.7139  381.0 0.0
'
unit 12012
'--- control blade (right)
 array  8001   -5.6350  -0.244     0.0
 cuboid 4 1  4.7625 -6.9061  2p0.3962  365.8 0.0
 cuboid 3 1  2p6.9061  2p0.7139  381.0 0.0
'
unit 12013
'--- control blade (intersection)
 cuboid 4 1  4p0.7139  365.8 0.0
 cuboid 3 1  4p0.7139  381.0 0.0
'
'
'-----------critical control blade---------------
unit 12022
'--- control blade (top)
 array  8004     -0.244  -4.6203  0.0
 cuboid 4 1  2p0.3962  6.9060 -4.7625  213.4  0.0
 cuboid 3 1  2p0.7139  2p6.9061  381.0 0.0
'
unit 12023
'--- control blade (bottom)
 array  8004     -0.244  -5.6350  0.0
 cuboid 4 1  2p0.3962  4.7625 -6.9060  213.4  0.0
 cuboid 3 1  2p0.7139  2p6.9061  381.0 0.0
'
unit 12024
'--- control blade (left)
 array  8003   -4.6203 -0.244     0.0
 cuboid 4 1  6.9060 -4.7625  2p0.3962  213.4  0.0
 cuboid 3 1  2p6.9061  2p0.7139  381.0 0.0
'
unit 12025
'--- control blade (right)
 array  8003   -5.6350  -0.244    0.0
 cuboid 4 1  4.7625 -6.9061  2p0.3962  213.4  0.0
 cuboid 3 1  2p6.9061  2p0.7139  381.0 0.0
'
unit 12026
'--- control blade (intersection)
 cuboid 4 1  4p0.7139  213.4  0.0
 cuboid 3 1  4p0.7139  381.0 0.0
'
'
global unit 13000
'--- reactor core
 array 9000  3*0.0
 reflector 3 1 6r30. 1
'
end geom
read array
ara=   1  nux=2  nuy=2  nuz=1 fill
     1     1     1     1   end fill
ara=   2  nux=2  nuy=4  nuz=1 fill
     1     2     1     1     1     1     1     2   end fill
ara=   3  nux=2  nuy=4  nuz=1 fill
     2     1     1     1     1     1     2     1   end fill
```

```
ara=   4  nux=4  nuy=2  nuz=1 fill
     2     1     1     2     1     1     1     1   end fill
ara=   5  nux=4  nuy=2  nuz=1 fill
     1     1     1     1     2     1     1     2   end fill
ara=   6  nux=3  nuy=3  nuz=1 fill
     5     9     5
     6     4     7
     5     8     5   end fill
ara=   7  nux=2  nuy=2  nuz=1 fill
    11    11    11    11   end fill
ara=   8  nux=2  nuy=4  nuz=1 fill
    11    12    11    11    11    11    11    12   end fill
ara=   9  nux=2  nuy=4  nuz=1 fill
    12    11    11    11    11    11    12    11   end fill
ara=  10  nux=4  nuy=2  nuz=1 fill
    12    11    11    12    11    11    11    11   end fill
ara=  11  nux=4  nuy=2  nuz=1 fill
    11    11    11    11    12    11    11    12   end fill
ara=  12  nux=3  nuy=3  nuz=1 fill
    15    19    15
    16    14    17
    15    18    15   end fill
ara=  13  nux=2  nuy=2  nuz=1 fill
    21    21    21    21   end fill
ara=  14  nux=2  nuy=4  nuz=1 fill
    21    22    21    21    21    21    21    22   end fill
ara=  15  nux=2  nuy=4  nuz=1 fill
    22    21    21    21    21    21    22    21   end fill
ara=  16  nux=4  nuy=2  nuz=1 fill
    22    21    21    22    21    21    21    21   end fill
ara=  17  nux=4  nuy=2  nuz=1 fill
    21    21    21    21    22    21    21    22   end fill
ara=  18  nux=3  nuy=3  nuz=1 fill
    25    29    25
    26    24    27
    25    28    25   end fill
ara=  19  nux=2  nuy=2  nuz=1 fill
    31    31    31    31   end fill
ara=  20  nux=2  nuy=4  nuz=1 fill
    31    32    31    31    31    31    31    32   end fill
ara=  21  nux=2  nuy=4  nuz=1 fill
    32    31    31    31    31    31    32    31   end fill
ara=  22  nux=4  nuy=2  nuz=1 fill
    32    31    31    32    31    31    31    31   end fill
ara=  23  nux=4  nuy=2  nuz=1 fill
    31    31    31    31    32    31    31    32   end fill
ara=  24  nux=3  nuy=3  nuz=1 fill
    35    39    35
    36    34    37
    35    38    35   end fill
ara=  25  nux=2  nuy=2  nuz=1 fill
    41    41    41    41   end fill
ara=  26  nux=2  nuy=4  nuz=1 fill
    41    42    41    41    41    41    41    42   end fill
ara=  27  nux=2  nuy=4  nuz=1 fill
    42    41    41    41    41    41    42    41   end fill
ara=  28  nux=4  nuy=2  nuz=1 fill
    42    41    41    42    41    41    41    41   end fill
ara=  29  nux=4  nuy=2  nuz=1 fill
    41    41    41    41    42    41    41    42   end fill
ara=  30  nux=3  nuy=3  nuz=1 fill
    45    49    45
    46    44    47
    45    48    45   end fill
ara=  31  nux=2  nuy=2  nuz=1 fill
    51    51    51    51   end fill
ara=  32  nux=2  nuy=4  nuz=1 fill
    51    52    51    51    51    51    51    52   end fill
ara=  33  nux=2  nuy=4  nuz=1 fill
    52    51    51    51    51    51    52    51   end fill
ara=  34  nux=4  nuy=2  nuz=1 fill
    52    51    51    52    51    51    51    51   end fill
```

```
ara=  35  nux=4  nuy=2  nuz=1 fill
    51    51    51    51    52    51    51    52   end fill
ara=  36  nux=3  nuy=3  nuz=1 fill
    55    59    55
    56    54    57
    55    58    55   end fill
ara=  37  nux=2  nuy=2  nuz=1 fill
    61    61    61    61   end fill
ara=  38  nux=2  nuy=4  nuz=1 fill
    61    62    61    61    61    61    61    62   end fill
ara=  39  nux=2  nuy=4  nuz=1 fill
    62    61    61    61    61    61    62    61   end fill
ara=  40  nux=4  nuy=2  nuz=1 fill
    62    61    61    62    61    61    61    61   end fill
ara=  41  nux=4  nuy=2  nuz=1 fill
    61    61    61    61    62    61    61    62   end fill
ara=  42  nux=3  nuy=3  nuz=1 fill
    65    69    65
    66    64    67
    65    68    65   end fill
ara=  43  nux=2  nuy=2  nuz=1 fill
    71    71    71    71   end fill
ara=  44  nux=2  nuy=4  nuz=1 fill
    71    72    71    71    71    71    71    72   end fill
ara=  45  nux=2  nuy=4  nuz=1 fill
    72    71    71    71    71    71    72    71   end fill
ara=  46  nux=4  nuy=2  nuz=1 fill
    72    71    71    72    71    71    71    71   end fill
ara=  47  nux=4  nuy=2  nuz=1 fill
    71    71    71    71    72    71    71    72   end fill
ara=  48  nux=3  nuy=3  nuz=1 fill
    75    79    75
    76    74    77
    75    78    75   end fill
ara=  49  nux=2  nuy=2  nuz=1 fill
    81    81    81    81   end fill
ara=  50  nux=2  nuy=4  nuz=1 fill
    81    82    81    81    81    81    81    82   end fill
ara=  51  nux=2  nuy=4  nuz=1 fill
    82    81    81    81    81    81    82    81   end fill
ara=  52  nux=4  nuy=2  nuz=1 fill
    82    81    81    82    81    81    81    81   end fill
ara=  53  nux=4  nuy=2  nuz=1 fill
    81    81    81    81    82    81    81    82   end fill
ara=  54  nux=3  nuy=3  nuz=1 fill
    85    89    85
    86    84    87
    85    88    85   end fill
ara=  55  nux=2  nuy=2  nuz=1 fill
    91    91    91    91   end fill
ara=  56  nux=2  nuy=4  nuz=1 fill
    91    92    91    91    91    91    91    92   end fill
ara=  57  nux=2  nuy=4  nuz=1 fill
    92    91    91    91    91    91    92    91   end fill
ara=  58  nux=4  nuy=2  nuz=1 fill
    92    91    91    92    91    91    91    91   end fill
ara=  59  nux=4  nuy=2  nuz=1 fill
    91    91    91    91    92    91    91    92   end fill
ara=  60  nux=3  nuy=3  nuz=1 fill
    95    99    95
    96    94    97
    95    98    95   end fill
ara=  61  nux=1  nuy=1  nuz=10 fill
    10    20    30    40    50
    60    70    80    90   100   end fill
ara=  62  nux=2  nuy=2  nuz=1 fill
   102   102   102   102   end fill
ara=  63  nux=2  nuy=4  nuz=1 fill
   102   103   102   102   102   102   102   103   end fill
ara=  64  nux=2  nuy=4  nuz=1 fill
   103   102   102   102   102   102   103   102   end fill
ara=  65  nux=4  nuy=2  nuz=1 fill
```

```
   103   102   102   103   102   102   102   102   end fill
ara=  66  nux=4  nuy=2  nuz=1 fill
   102   102   102   102   103   102   102   103   end fill
ara=  67  nux=3  nuy=3  nuz=1 fill
   106   110   106
   107   105   108
   106   109   106   end fill
   .
   .
   .


   (16,431 lines deleted)


   .
   .
   .
'
'--- control rod b4c arrays
' fully inserted
ara=8001 nux=21 nuy=1 nuz=1 fill 21r12004  end fill
ara=8002 nux=1 nuy=21 nuz=1 fill 21r12004  end fill
' critical height rod
ara=8003 nux=21 nuy=1 nuz=1 fill 21r12005  end fill
ara=8004 nux=1 nuy=21 nuz=1 fill 21r12005  end fill
'
'--- reactor core array - layout map
ara=9000  nux=59 nuy=59 nuz=1 fill
 12000 12001 12000 12001 12000 12001 12000 12001 12000 12001
 12000 12001 12000 12001 12000 12001  8787 12009  7878 12001
  6868 12009 11716 12001  4343 12009  2929 12001 11615 12009
 11615 12001  2929 12009  4343 12001 11716 12009  6868 12001
  7878 12009  8787 12001 12000 12001 12000 12001 12000 12001
 12000 12001 12000 12001 12000 12001 12000 12001 12000 12002
 12003 12002 12003 12002 12003 12002 12003 12002 12003 12002
 12003 12002 12003 12002 12003 12011 12013 12012 12003 12011
 12013 12012 12003 12011 12013 12012 12003 12011 12013 12012
 12003 12011 12013 12012 12003 12011 12013 12012 12003 12011
 12013 12012 12003 12002 12003 12002 12003 12002 12003 12002
 12003 12002 12003 12002 12003 12002 12003 12002 12000 12001
 12000 12001 12000 12001 12000 12001 12000 12001 12000 12001
 12000 12001  9797 12001  8686 12010  7777 12001  6767 12010
  5555 12001  4242 12010  2828 12001 11514 12010 11514 12001
  2828 12010  4242 12001  5555 12010  6767 12001  7777 12010
  8686 12001  9797 12001 12000 12001 12000 12001 12000 12001
 12000 12001 12000 12001 12000 12001 12000 12002 12003 12002
 12003 12002 12003 12002 12003 12002 12003 12002 12003 12002
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 12003 12002 12003 12002 12003 12002 12000 12001 12000 12001
 12000 12001 12000 12001 12000 12001 11413 12001 11312 12009
  9696 12001  8585 12001  7676 12001  6666 12009  5454 12001
  4141 12001  2727 12001  1313 12009  1313 12001  2727 12001
  4141 12001  5454 12009  6666 12001  7676 12001  8585 12001
  9696 12009 11312 12001 11413 12001 12000 12001 12000 12001
 12000 12001 12000 12001 12000 12002 12003 12002 12003 12002
 12003 12002 12003 12002 12003 12002 12003 12011 12013 12012
 12003 12002 12003 12002 12003 12011 12013 12012 12003 12002
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 12013 12012 12003 12002 12003 12002 12003 12002 12003 12002
 12003 12002 12003 12002 12000 12001 12000 12001 12000 12001
 12000 12001 12000 12001 10807 12001 11211 12010  9595 12001
  8484 12001  7575 12001  6565 12010  5353 12001  4040 12001
  2626 12001 11110 12010 11110 12001  2626 12001  4040 12001
  5353 12010  6565 12001  7575 12001  8484 12001  9595 12010
 11211 12001 10807 12001 12000 12001 12000 12001 12000 12001
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end array
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read plot pic=mat
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uax=1 vdn=-1 nax=300 end plot
end data
end
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